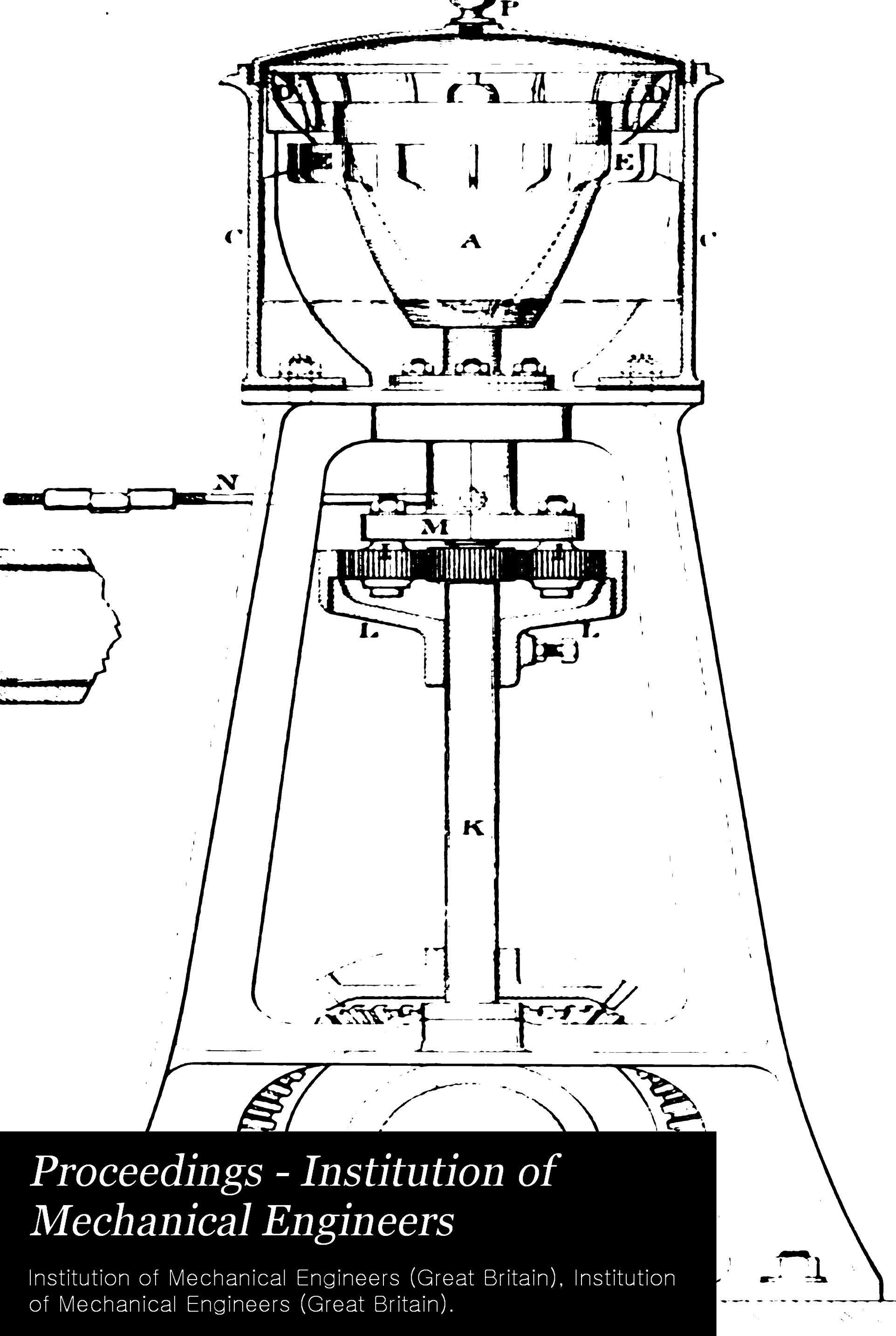

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INSTITUTION

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PROCEEDINGS.

1866.

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1866.

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WITH YEAR OF ELECTION.

1866.

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1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1866. Adams, William, Locomotive Superintendent, North London Railway, Bow, London, E.
1848. Adams, William Alexander, Newbold Beeches, Leamington.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1847. Allan, Alexander, Bridge Street, Worcester.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1865. Alleyne, John Gay Newton, Butterley Iron Works, Alfreton.
1859. Alton, George, Midland Road, Derby.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.
1856. Anderson, John, Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Erith Iron Works, Erith, Kent, S.E.
1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.
1858. Appleby, Charles Edward, Renishaw Iron Works, near Chesterfield.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1866. Armstrong, George, Great Western Railway, Locomotive Department, Wolverhampton.
1863. Armstrong, John, Timber Works, 17 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.
1858. Armstrong, Sir William George, Elswick, Newcastle-on-Tyne.
1857. Ashbury, James Lloyd, 9 Sussex Place, Hyde Park Gardens, London, W.
1848. Ashbury, John, Openshaw Works, near Manchester.
1858. Atkinson, Charles, Fitzalan Steel Works, Sheffield.

1865. Bagshawe, John J., Thames Steel Works, Sheffield.
1865. Bailey, John, Blackhall Place Iron Works, Dublin.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1866. Baines, William, London Works, Soho, near Birmingham.
1866. Baker, Samuel, 22 Oil Street, Liverpool.
1865. Baldwin, Martin, Bovereux Iron Works, Bilston.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1865. Barclay, William, 4 College Lane, Liverpool.
1866. Barker, George, Messrs. Barker and Cope, Kidsgrove, Stoke-upon-Trent.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1863. Barlow, Edward, Messrs. Dobson and Barlow, Kay Street Works, Bolton.
1866. Barnard, Clement, 2 Staples Inn, Holborn, London, W.C.
1862. Barrow, Joseph, Whalley Chambers, 88 King Street, Manchester.
1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth, near Lancaster.
1865. Bass, William, Solway Screw Bolt and Rivet Works, Workington.
1859. Bastow, Samuel, Cliff House Iron Works, West Hartlepool.
1860. Batho, William Fothergill, Messrs. Nettlefold and Chamberlain, Smethwick Screw Works, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington.
1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.
1864. Beckton, James George, Whitby.
1865. Bell, Charles, North Staffordshire Railway, Locomotive Department, Stoke-upon-Trent.
1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1865. Bell, John, Belmont House, Timperley, near Manchester.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1865. Bennett, Henry, Wombridge Iron Works, near Wellington, Shropshire.
1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.
1865. Benson, George Henry, Stalybridge.
1865. Benson, Martin, 14 Hinde Street, Manchester Square, London, W.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.
1866. Bevis, Restel Ratsey, Birkenhead Iron Works, Birkenhead.
1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1863. Birckel, John James, Regent's Canal Iron Works, Eagle Wharf Road, London, N.

1866. Birkbeck, John Addison, Sheepbridge Iron Works, Chesterfield.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.

1851. Blackwell, Samuel Holden, Dudley.

1865. Bladen, Charles, Provan Mill House, Springburn, near Glasgow.

1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.

1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.

1862. Bouch, Thomas, 78 George Street, Edinburgh.

1858. Bouch, William, Shildon Engine Works, Darlington.

1847. Bovill, George Hinton, 24 Duke Street, Westminster, S.W.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

1862. Boyd, Nelson, Belfast Foundry, Donegal Street, Belfast.

1854. Bragge, William, Atlas Steel and Iron Works, Sheffield.

1854. Bramwell, Frederick Joseph, 37 Great George Street, Westminster, S.W.

1861. Brierly, Henry, 27 Southampton Buildings, London, W.C.

1848. Broad, Robert, Horseley Iron Works, near Tipton.

1865. Brock, Walter, Vulcan Foundry, Glasgow.

1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)

1866. Brown, Andrew Betts, Vauxhall Iron Works, London, S.

1866. Brown, Charles James, Unity Chambers, Temple Street, Birmingham.

1865. Brown, George, Rotherham Iron Works, Rotherham.

1863. Brown, Henry, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.

1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1850. Brown, John, Atlas Steel and Iron Works, Sheffield.

1855. Brown, John, Mining Engineer, Barnsley.

1853. Brown, Ralph, Patent Shaft Works, Wednesbury.

1865. Bryant, Frederick William, Blackfriars Bridge Works, Chatham Place, London, E.C.

1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.

1858. Burn, Henry, Midland Railway, Locomotive Department, Derby.

1856. Butler, Ambrose Edmund, Kirkstall Forge, Leeds.

1863. Butler, Arthur, Surdah, Radshye, Lower Bengal, India: (or care of W. J. Butler, Chipping Hill, Witham).

1859. Butler, John, Stanningley Iron Works, near Leeds.

1859. Butler, John Octavius, Kirkstall Forge, Leeds.

1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1864. Campbell, David, 20 Castle Street, Liverpool.
1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1860. Cannell, Fleetwood James, Old Park Iron Works, Wednesbury.
1860. Carbutt, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1865. Carlton, Samuel, Great Western Railway, Locomotive Department, Swindon.
1862. Carpmael, William, 24 Southampton Buildings, London, W.C.
1866. Carpmael, William, Jun., 24 Southampton Buildings, London, W.C.
1856. Carrett, William Elliott, Sun Foundry, Leeds.
1864. Carrington, William Thomas, St. Leonard's Iron Works, Perth.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1865. Cartwright, John, New Bond Street Iron Works, Birmingham.
1866. Chapman, Henry, 41 Boulevard Malesherbes, Paris.
1857. Chrimes, Richard, Brass Works, Rotherham.
1866. Claridge, Thomas, Phœnix Foundry, near Bilston.
1854. Clark, Daniel Kinnear, 11 Adam Street, Adelphi, London, W.C.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Knott Mill Iron Works, Manchester.
1865. Clarke, John, Railway Foundry, Jack Lane, Leeds.
1859. Clay, William, Mersey Steel and Iron Works, Sefton Street, Liverpool.
1863. Clayton, Robert, Soho Foundry, Preston.
1866. Cleworth, Charles, Assistant Locomotive Superintendent, East Indian Railway, Jumalpore, India.
1847. Clift, John Edward, Prospect Hill, Redditch.
1860. Clunes, Thomas, Worcester Engine Works, Worcester.
1865. Coates, Victor, Lagan Iron Works, Belfast.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1847. Coke, Richard George, Mining Engineer, Chesterfield.
1864. Colburn, Zerah, 7 Gloucester Road, Regent's Park, London, N.W.
1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1860. Cope, James, Mining Engineer, Pensnett, near Dudley.
1865. Corlett, Henry Lee, Great Southern and Western Railway, Carriage Department, Dublin.
1848. Corry, Edward, 8 New Broad Street, London, E.C.

1857. Cortazzi, Francis James, care of Hugh Hornby, Sandown, Wavertree, Liverpool.
1860. Coulthard, Hiram Craven, Park Iron Works, Blackburn.
1864. Cowans, John, St. Nicholas and Woodbank Iron Works, Carlisle.
1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
1862. Cox, Samuel H. F., 3 East Parade, Sheffield.
1863. Craig, Andrew, 6 Cecil Place, Paisley Road, Glasgow.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.
1858. Crawhall, Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.
1865. Cross, James, St. Helen's Locomotive Works, St. Helen's.
1863. Crow, George, Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1864. Crowe, Edward, Tees Side Iron Works, Middlesbrough.
1858. Cubitt, Charles, 3 Great George Street, Westminster, S.W.
1865. Curtis, Matthew, Phœnix Foundry, Chapel Street, Manchester.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
1866. Daniel, Edward Freer, Abbey Iron Works, Shrewsbury.
1866. Daniel, William, St. John's Hill, Shrewsbury.
1865. Darby, Abraham, Ebbw Vale Iron Works, near Tredegar.
1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich, S.E.
1865. Davies, Benjamin, Huyton Bleach Works, near Chorley.
1863. Davy, Alfred, Park Iron Works, Sheffield.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, South Hetton, near Fence Houses.
1866. Death, Ephraim, Albert Works, Leicester.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1864. Dewhurst, John, Lancashire Steel Works, Gorton, Manchester.
1865. Dircks, Henry, 48 Charing Cross, London, S.W. (*Life Member.*)
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.
1865. Dobson, Benjamin, Messrs. Dobson and Barlow, Kay Street Works, Bolton.
1865. Domville, Charles Kelloch, Resident Engineer and Locomotive Superintendent, Belfast and County Down Railway, Belfast.
1865. Douglas, Charles P., Consett Iron Works, near Gateshead.
1857. Douglas, George K., Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.

1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1866. Downey, Alfred C., Ormesby Iron Works, Middlesbrough.
1847. Dubs, Henry, Glasgow Locomotive Works, Glasgow.
1857. Dunlop, John Macmillan, Holehird, Windermere.
1854. Dunn, Thomas, 26 Market Street, Manchester.
1864. Dunn, Thomas Edward, Jumna Bridge, East Indian Railway, Allahabad, India: (or care of R. Dunn, Howick, Bilton, Northumberland.)
1861. Dutton, Charles, Bromford Iron Works, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.
1865. Dyson, Robert, Phœnix Wheel Tyre and Axle Works, Rotherham.

1859. Eassie, Peter Boyd, Railway Saw Mills, Gloucester.
1858. Easton, Edward, Grove Works, Southwark, London, S.E.
1856. Eastwood, James, Railway Iron Works, Derby.
1866. Elce, John, Phœnix Iron Works, Manchester.
1862. Elder, John, Messrs. Randolph Elder and Co., Centre Street, Glasgow.
1859. Elliot, George, Houghton-le-Spring, near Fence Houses.
1865. Elliot, Walter, Civil Engineer to the Colonial Government, Gibraltar.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1853. England, George, Hatcham Iron Works, London, S.E.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1864. Etienne, Antonin, Engineer, Cordova and Seville Railway, Seville, Spain.
1857. Evans, John Campbell, Morden Iron Works, East Greenwich, S.E.
1848. Everitt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.
1864. Everitt, William Edward, Kingston Metal Works, Adderley Street, Birmingham.
1865. Evers, Frank, Cradley Iron Works, near Stourbridge.

1857. Fairlie, Robert Francis, 56 Gracechurch Street, London, E.C.
1865. Faviell, Samuel Clough, Clarence Iron Works, Leeds.
1866. Fenby, Joseph Beverley, 67 Camden Street, Parade, Birmingham.
1854. Fernie, John, Clarence Iron Works, Leeds.
1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.
1861. Field, Joshua, Cheltenham Place, Lambeth, London, S.
1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.
1864. Fleet, Thomas, Crown Boiler Works, Westbromwich.
1861. Fleetwood, Daniel Joseph, 58 Broad Street, Birmingham.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.

1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven. (*Life Member.*)

1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1866. Fletcher, James, Jun., Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1859. Fogg, Robert, 17 Park Street, Westminster, S.W.

1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.

1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.

1864. Foster, Edward Henry, Old Park Hall, Walsall.

1861. Foster, Sampson Lloyd, Old Park Iron Works, Wednesbury.

1847. Fothergill, Benjamin, 27 Cornhill, London, E.C.

1866. Fowler, George, Mining Engineer, Ashby-de-la-Zouch.

1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.

1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.

1866. Fox, Charles Douglas, 8 New Street, Spring Gardens, London, S.W.

1864. Frankish, John, 1 Lord's Chambers, Corporation Street, Manchester.

1859. Fraser, John, 18 York Place, Leeds.

1866. Fraser, John Simpson, Carriage and Wagon Superintendent, Great Western Railway, Paddington, London, W.

1856. Freeman, Joseph, 98 Cannon Street, London, E.C.

1864. Frost, Thomas, Canal Street Iron Works, Derby.

1852. Froude, William, Elmsleigh, Paignton, Torquay.

1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1865. Gainsford, William Dunn, Sheffield Coal Co., Sheffield.

1866. Galloway, Charles John, Knott Mill Iron Works, Manchester.

1862. Galton, Capt. Douglas, R.E., War Office, Pall Mall, London, S.W.

1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1848. Gibbons, Benjamin, Hill Hampton House, near Stourport.

1865. Gibbs, William, Deepfields Iron Works, near Wolverhampton.

1856. Gilkes, Edgar, Tees Engine Works, Middlesbrough.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.

1865. Göransson, Göran Fredrick, Steel Works, Gefle and Hägbo, Sweden.

1865. Gray, John McFarlane, Vauxhall Foundry, Liverpool.

1848. Green, Charles, Tube Works, Leek Street, Birmingham.

1861. Green, Edward, Jun., 14 St. Ann's Square, Manchester.

1858. Greenwood, Thomas, Albion Works, Armley Road, Leeds.

1857. Gregory, John, Engineer, Portuguese National Railway South of Tagus, Barriero, near Lisbon, Portugal.

1865. Greig, David, Steam Plough Works, Leeds.
1866. Grice, Edwin James, Stour Valley Works, Spon Lane, Westbromwich.
1860. Grice, Frederic Groom, Stour Valley Works, Spon Lane, Westbromwich.
1866. Gurden, Charles Frederick, Superintendent Engineer, Brazil and River Plate Steam Boat Co., 43 Canning Street, Birkenhead.

1863. Hackney, William, 3 Great George Street, Westminster, S.W.
1861. Haden, William, Dixon's Green, Dudley.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1864. Halkett, John Craigie, Cramond Iron Works, Edinburgh.
1863. Hall, Joseph, Gratz Iron Works, Gratz, Styria, Austria.
1857. Hall, William, 167 Dartmouth Street, Birmingham.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1858. Harding, John, Beeston Manor Iron Works, Leeds.
1859. Harman, Henry William, Canal Street Works, Manchester.
1856. Harrison, George, Canada Works, Birkenhead.
1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.
1865. Harrison, William, Bank Foundry, Blackburn.
1865. Harrison, William Arthur, Cambridge Street Works, Manchester.
1863. Hartas, Isaac, Rosedale Iron Mines, near Pickering, Yorkshire.
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1857. Haughton, S. Wilfred, Greenbank, Carlow. (*Life Member.*)
1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1848. Hawthorn, Robert, Forth Banks, Newcastle-on-Tyne.
1848. Hawthorn, William, Forth Banks, Newcastle-on-Tyne.
1862. Haynes, Thomas John, Calpe Foundry, North Front, Gibraltar.
1860. Head, John, Messrs. Ransomes and Sims, Orwell Works, Ipswich.
1858. Head, Thomas Howard, 9 Dowgate Hill, London, E.C.
1853. Headly, James Ind, Eagle Foundry, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1862. Heath, William J. W., Assistant Engineer, Ceylon Railway, Colombo, Ceylon: (or care of John J. Heath, 105 Vyse Street, Birmingham).
1864. Heathfield, Richard, Lion Galvanising Works, Birmingham Heath, Birmingham.
1860. Heaton, George, Royal Copper Mint, Icknield Street East, Birmingham.
1865. Heptinstall, John, Rotherham Iron Works, Rotherham.
1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.
1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.

1864. Hetherington, William Isaac, Vulcan Works, Pollard Street, Manchester.
1866. Hickman, George Haden, Groveland Iron Works, Dudley Port, Tipton.
1864. Hide, Thomas C., 46 Fenchurch Street, London, E.C.
1863. Hind, Roger, Scotland Bank Iron Works, Warrington.
1862. Hingley, Samuel, Hart's Hill Iron Works, near Brierley Hill.
1866. Hodgson, Charles, 40 Avenue du Roi de Rome, Paris.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Shut End, Brierley Hill.
1866. Holcroft, Thomas, Bilston Foundry, Bilston.
1865. Holliday, John, Messrs. Bethell's Creosote Works, Westbromwich.
1863. Holt, Francis, Gorton Foundry, Manchester.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, Tees Side Iron Works, Middlesbrough.
1866. Hopkins, John Satchell, Tinplate Works, Granville Street, Birmingham.
1856. Hopkinson, John, London Road Iron Works, Manchester.
1858. Hopper, George, Houghton-le-Spring Iron Works, near Fence Houses.
1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.
1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.
1858. Hosking, John, Gateshead Iron Works, Gateshead.
1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.
1864. Howard, Elliot, 84 Upper Whitecross Street, London, E.C.
1860. Howard, James, Britannia Iron Works, Bedford.
1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1861. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.
1866. Hoyle, William Jennings, Messrs. Whitworth and Co., Chorlton Street, Manchester.
1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.
1847. Humphrys, Edward, Deptford Pier, London, S.E.
1859. Hunt, James P., Gospel Oak Iron Works, Tipton.
1856. Hunt, Thomas, 23 West Cliff, Preston.
1864. Hutchinson, Edward, Skerne Iron Works, Darlington.
1863. Hutton, Walter Stuart, Prospect Works, Hunslet Lane, Leeds.
1865. Hyde, Lt.-Colonel Henry, R.E., Master of the Mint, Calcutta: (or care of Rev. H. M. C. Hyde, Camberwell, London, S.) (*Life Member.*)

1857. Inshaw, John, Engine Works, Morville Street, Birmingham.
1866. Ireland, William, 41 Beech Lane, Macclesfield.

1865. Jackson, John, Harbour of Refuge Works, Alderney.
1859. Jackson, Matthew Murray, Messrs. Escher Wyss and Co., Engine Works, Zurich, Switzerland.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1861. Jackson, Robert, Ætna Steel Works, Sheffield.
1860. Jackson, Samuel, Cyclops Steel and Iron Works, Sheffield.
1866. Jaeger, Herrmann Frederic, Gorton Foundry, Manchester.
1858. Jaffrey, George William, Hartlepool Iron Works, Hartlepool.
1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.
1865. Jarvis, Edward George, Park, Gloucester.
1855. Jeffcock, Parkin, Mining Engineer, Midland Road, Derby.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.
1857. Jenkins, William, Locomotive Superintendent, Lancashire and Yorkshire Railway, Miles Platting, Manchester.
1861. Jessop, Thomas, Park Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1863. Johnson, Bryan, Flookersbrook Foundry, Chester.
1847. Johnson, James, North Staffordshire Railway, Engineer's Office, Stoke-upon-Trent.
1861. Johnson, Samuel Waite, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.
1861. Jones, David, Engineer, Rumney Railway, Machen, near Newport, Monmouthshire.
1847. Jones, Edward, The Larches, Handsworth, near Birmingham.
1857. Jones, Hodgson, 67 Victoria Street, Westminster, S.W.
1853. Joy, David, Cleveland Engine Works, Middlesbrough.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.
1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1857. Kennedy, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway; 45 Finsbury Circus, London, E.C.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway; 45 Finsbury Circus, London, E.C.
1866. Kershaw, John, 24 Duke Street, Westminster, S.W.
1865. Kirkaldy, David, Testing and Experimental Works, The Grove, Southwark Street, London, S.E.
1848. Kirkham, John, 109 Euston Road, London, N.W.
1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1864. Kirtley, William, Midland Railway, Locomotive Department, Derby.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.

1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1866. Knap, Conrad, 5 Bridge Street, Westminster, S.W.
1863. Knight, Thomas, 130 Bradford Street, Birmingham.

1866. Lambert, William Blake, Berwick-upon-Tweed.
1863. Lancaster, John, Kirkless Hall Coal and Iron Works, near Wigan.
1863. Latham, Ernest, 11 Park Grove, Bromley, Kent, S.E.
1860. Law, David, Phœnix Iron Works, Glasgow.
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Locomotive Superintendent, Monmouthshire Railway and Canal Company, Newport, Monmouthshire.
1860. Lea, Henry, 35 Paradise Street, Birmingham.
1865. Ledger, Joseph, West Cumberland Hæmatite Iron Works, Workington.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Junction Works, Miles Platting, Manchester.
1865. Leigh, Frederick Allen, Junction Works, Miles Platting, Manchester.
1866. Leigh, Joseph, Ellesmere Foundry, Patricroft, near Manchester.
1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1856. Levick, Frederick, Cwm-Celyn Blaina and Coalbrook Vale Iron Works, near Newport, Monmouthshire.
1860. Lewis, Thomas William, Plymouth Iron Works, Merthyr Tydvil.
1864. Lindsley, George, Great Western Railway, Locomotive Department, Swindon.
1856. Linn, Alexander Grainger, 2 Queen Square Place, Westminster, S.W.
1857. Little, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1866. Little, George, Hartford Iron Works, Oldham.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1866. Lloyd, Joseph Foster, Darlaston Green Iron and Steel Works, near Wednesbury.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1864. Lloyd, Sampson Zachary, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Old Park Iron Works, Wednesbury.
1862. Lloyd, Wilson, Moor Hall, Sutton Coldfield, near Birmingham.
1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, 67 King Street, Manchester.

1865. Longridge, William Smith, Alderwasley Iron Works, Ambergate, near Derby.
1866. Lord, Edward, Canal Street Works, Todmorden.
1859. Lord, Thomas Wilks, Bank Mills, Leeds.
1861. Low, George, St. Peter's Iron Works, Ipswich.
1865. Lundh, Sverier Hakon, 9B New Broad Street, London, E.C.
1854. Lynde, James Gascoigne, Town Hall, Manchester.

1864. Macfarlane, Walter, Saracen Foundry, Glasgow.
1856. Mackay, John, Mount Hermon, Drogheda.
1864. Macnab, Archibald Francis, Peninsular and Oriental Steam Navigation Co., Hong-Kong, China: (or care of C. Hall, P. and O. S. N. Co., Southampton.)
1865. MacNay, William, Shildon Engine Works, Darlington.
1865. Macnee, Daniel, Cyclops Steel and Iron Works, Sheffield.
1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.
1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.
1862. Mappin, Frederick Thorpe, Sheaf Works, Sheffield.
1857. March, George, Union Foundry, Leeds.
1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1865. Marshall, Francis Carr, Jarrow Engine Works, Quayside, Newcastle-on-Tyne.
1862. Marshall, James, 4 Gloucester Terrace, Rye Hill, Newcastle-on-Tyne.
1859. Marshall, William Ebenezer, Sun Foundry, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Engineer, Stourbridge Water Works, 13 High Street, Stourbridge.
1853. Marten, Henry, Parkfield Iron Works, near Wolverhampton.
1857. Martindale, Capt. Ben Hay, R.E., War Office, Pall Mall, London, S.W.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1864. Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.
1857. Masselin, Armand, Glass Works, Folembray, Aisne, France.
1853. Mathews, William, North Grove, Great Malvern.
1848. Matthew, John, Messrs. John Penn and Co., Marine Engineers, Greenwich, S.E.
1847. Matthews, William Anthony, Sheaf Works, Sheffield.
1853. Maudslay, Henry, Bystock, near Exmouth. (*Life Member.*)
1864. Maudslay, Thomas Henry, Cheltenham Place, Lambeth, London, S.
1861. May, Robert Charles, 3 Great George Street, Westminster, S.W.

1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.
1865. Maylor, John, Engineer and Shipbuilder, Rio de Janeiro, Brazil: 11 Commerce Chambers, Lord Street, Liverpool.
1859. Maylor, William, East Indian Iron Works, Beypoor, India: (or care of E. J. Burgess, Abchurch Chambers, Abchurch Yard, London, E.C.)
1847. McClean, John Robinson, 23 Great George Street, Westminster, S.W.
1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.
1864. McEwen, Lawrence Thompson, Ormesby Iron Works, Middlesbrough.
1860. McKenzie, James, Well House Foundry, Leeds.
1859. McKenzie, John, Worcester Engine Works, Worcester.
1862. McPherson, Hugh, Ethelbert Villa, Kingsholme, Gloucester.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.
1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.
1866. Meredith, Alban, 107 Lionel Street, Birmingham.
1857. Metford, William Ellis, Flook House, Taunton.
1847. Middleton, William, Vulcan Iron Foundry, Summer Lane, Birmingham.
1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1862. Millward, John, 27 Paradise Street, Birmingham.
1856. Mitchell, Charles, The Grange, Surbiton Hill, Kingston-on-Thames.
1858. Mitchell, James, 3 Church Terrace, Higher Tranmere, Birkenhead.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1864. Moore, Sampson, North Foundry, Cotton Street, Clarence Dock, Liverpool.
1864. Morgan, Joshua Llewelyn, Kingscombe, near Cowbridge.
1849. Morrison, Robert, Ouseburn Engine Works, Newcastle-on-Tyne.
1865. Morton, Robert, Brass Works, Stockton-on-Tees.
1865. Mosse, James Robert, Mauritius Railways, Port Louis, Mauritius.
1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
1866. Muir, Andrew, Britannia Works, Sherborne Street, Strangeways, Manchester.
1863. Muir, William, 57 Claverton Street, Pimlico, London, S.W.
1857. Muntz, George Frederick, French Walls, near Birmingham.
1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness, Lancashire.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1848. Napier, John, Vulcan Foundry, Glasgow.

1856. Napier, Robert, West Shandon, Helensburgh, near Glasgow. (*Life Member.*)

1861. Naylor, John William, Wellington Foundry, Leeds.

1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.

1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.

1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.

1856. Newall, James, East Lancashire Railway, Carriage Department, Bury, Lancashire.

1866. Newdigate, Albert Lewis, care of Charles P. B. Shelley, 21 Parliament Street, Westminster, S.W.

1862. Newton, William Edward, 66 Chancery Lane, London, W.C.

1858. Nichol, Peter Dale, care of Anthony Nichol, 19 Quay, Newcastle-on-Tyne.

1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.

1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.

1866. Oliver, William, Victoria Foundry, Chesterfield.

1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1847. Owen, William, Phœnix Wheel Tyre and Axle Works, Rotherham.

1865. Parkes, Alexander, Stephenson Metal Tube Works, Liverpool Street, Birmingham.

1860. Parkin, John, Harvest Lane Steel Works, Sheffield.

1866. Parton, Thomas, Rough Hay Iron Works, Darlaston, near Wednesbury.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1848. Pearson, John, 7 Old Hall Street, Liverpool.

1866. Peel, George, Jun., Soho Iron Works, Pollard Street, Manchester.

1866. Peele, Arthur John, New Cross Works, Deptford, London, S.E.

1848. Penn, John, The Cedars, Lee, Kent, S.E. (*Life Member.*)

1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.

1866. Perks, John Hartley, Shrubbery Iron Works, Wolverhampton.

1856. Perring, John Shae, 104 King Street, Manchester.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.

1860. Peyton, Edward, Bordesley Works, Birmingham.

1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.

1854. Pilkington, Richard, Jun., Wolsingham, near Darlington.

1859. Pitts, Joseph, Stanningley Iron Works, near Leeds.

1859. Platt, John, M.P., Hartford Iron Works, Oldham.

1862. Player, John, Norton, near Stockton-on-Tees.
1866. Plum, Thomas Edward Day, Atlas Works, Manchester.
1861. Plum, Thomas William, Ravensdale Iron Works, Tunstall, near Stoke-upon-Trent.
1856. Pollard, John, Midland Junction Foundry, Leeds.
1860. Ponsonby, Edward Vincent, Engineer, Great Western Railway, Worcester.
1866. Porter, Charles Talbot, Messrs. Whitworth and Co., Chorlton Street, Manchester.
1852. Porter, John Henderson, 7 St. Mildred's Court, Poultry, London, E.C.
1861. Porter, Robert, Ebro Works, Tividale, near Tipton.
1864. Potts, Benjamin Langford Foster, 200 Camberwell Grove, London, S.
1851. Potts, John Thorpe, 200 Camberwell Grove, London, S.
1865. Pratchitt, William, Denton Iron Works, Carlisle.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.
1866. Price, John, Chief Surveyor, Underwriters' Registry for Iron Vessels, 42 Villiers Street, Sunderland.
1866. Putnam, William, Darlington Forge, Darlington.

1862. Rake, Alfred Stansfield, Bank Buildings, Newcastle-on-Tyne.
1864. Ramage, Robert, Locomotive Superintendent, Midland Great Western Railway, Dublin.
1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
1866. Ramsden, James, Abbott's Wood, Barrow-in-Furness, Lancashire.
1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.
1862. Ransome, Robert James, Orwell Works, Ipswich.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.
1862. Reynolds, Edward, Don Steel Works, Sheffield.
1866. Reynolds, Frederic Cornell, 37 Great George Street, Westminster, S.W.
1866. Richards, Edward Windsor, Ebbw Vale Iron Works, near Tredegar.
1863. Richards, Edwin, Tredegar Iron Works, Tredegar.
1865. Richards, Job, Rabone Bridge Iron Works, Smethwick, near Birmingham.
1856. Richards, Josiah, Abersychan Iron Works, Pontypool.
1863. Richardson, Edward, Lyttelton and Christchurch Railway, Christchurch, New Zealand.
1865. Richardson, John, Borough Engineer, Town Hall, Halifax.
1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.
1859. Richardson, William, Hartford Iron Works, Oldham.
1865. Rideal, Samuel, 18 Hopwood Avenue, Manchester.
1863. Rigby, Samuel, Cock Hedge Mill, Warrington.

1848. Robertson, Henry, Great Western Railway, Shrewsbury.
1865. Robey, Robert, Perseverance Iron Works, Lincoln.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1865. Robinson, John, Railway Works, Rochdale.
1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.
1866. Rose, Thomas, Bradley Iron Works, near Bilston.
1866. Rosthorn, Joseph De, 25 Turkenstrasse, Alsergrund, Vienna.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Boston.
1857. Routledge, William, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1860. Rumble, Thomas William, 5 Westminster Chambers, Victoria Street, Westminster, S.W. (*Life Member.*)
1847. Russell, John Scott, 20 Great George Street, Westminster, S.W.
1863. Ryder, William, Bark Street, Bolton.

1866. Sacré, Alfred, Yorkshire Engine Co., Meadow Hall Works, near Sheffield.
1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1864. Said, Colonel M., Bey, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.
1848. Samuel, James, 26 Great George Street, Westminster, S.W.
1857. Samuelson, Alexander, 27 Cornhill, London, E.C.
1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.
1857. Samuelson, Martin, Engine Works, Neptune Street, Hull.
1865. Sandberg, Christer Peter, Engineer, Swedish Government Railway Service, Stockholm, Sweden: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1861. Sanderson, George Grant, Parkgate Iron Works, Rotherham.
1864. Sanderson, John, Locomotive Superintendent, Whitehaven Cleator and Egremont Railway, Moor Row, near Whitehaven.
1860. Schneider, Henry William, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.
1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.
1865. Scott, Edward, 10 Tib Lane, Cross Street, Manchester.
1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of Joseph Reid 49 Arundel Square, London, N.)

1864. Seddon, John, 31 King Street, Wigan.
1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1865. Sellers, William, Pennsylvania Avenue, Philadelphia, United States.
1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.
1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.
1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.
1864. Shaw, Duncan, Mining Engineer, Cordova, Spain.
1866. Shaw, Frank, Burton Iron Works, Burton-on-Trent.
1856. Shelley, Charles Percy Bysshe, 21 Parliament Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1859. Shuttleworth, Joseph, Stamp End Iron Works, Lincoln.
1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.
1862. Silvester, John, Messrs. George Salter and Co., Spring Balance Works, Westbromwich.
1847. Sinclair, Robert, Great Eastern Railway, Stratford, London, E.
1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.
1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.
1853. Slaughter, Edward, Avonside Engine Works, Bristol.
1866. Smethurst, Joseph, Messrs. Martin and Smethurst, Guide Bridge, near Ashton-under-Lyne.
1866. Smith, Edward Fisher, Coneygre Iron Works, Dudley Port, Dudley.
1866. Smith, Fereday, Bridgewater Offices, Manchester.
1854. Smith, George, Wellington Road, Dudley.
1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1858. Smith, Isaac, 36 Lancaster Street, Birmingham.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.
1859. Smith, Matthew, Caledonia Wire Mills, Halifax.
1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.
1866. Smith, William, Eglinton Engine Works, Glasgow.
1863. Smith, William Ford, Gresley Iron Works, Ordsal Lane, Salford, Manchester.
1857. Snowdon, Thomas, 147 High Street, Stockton-on-Tees.
1859. Sokoloff, Capt. Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1863. Somerville, Wallace Cochrane, London Works, Birmingham.
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.

1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.
1866. Spencer, Eli, Hartford Iron Works, Oldham.
1859. Spencer, John Frederick, Sunderland Engine Works, South Dock, Sunderland.
1853. Spencer, Thomas, Clough Hall Iron Works, Kidsgrove, near Stoke-upon-Trent.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.
1862. Stableford, William, Oldbury Carriage Works, near Birmingham.
1866. Stephens, John Classon, Blackhall Place Iron Works, Dublin.
1866. Stevenson, John, Acklam Iron Works, Middlesbrough.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1864. Stokes, James Folliott, Meole Brace, Shrewsbury.
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Cawnpore, India.
1865. Stroudley, William, Locomotive Superintendent, Highland Railway, Inverness.
1861. Sumner, William, 21 Clarence Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.
1864. Swindell, James Swindell Evers, Cradley Iron Works, near Brierley Hill.
1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Soho, near Birmingham.
1859. Tannett, Thomas, Victoria Foundry, Leeds.
1861. Taylor, George, Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)
1864. Thomas, Thomas, Llynvi Vale Iron Works, near Bridgend.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.
1852. Thomson, George, Crookhay Iron Works, Westbromwich.
1865. Thorn, Alexander, Steam Saw Mills, Chelsea, London, S.W.

1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1865. Tickle, John, Providence Engine Works, Westbromwich.
1862. Tijou, William, 27 Great George Street, Westminster, S.W.
1861. Tipping, Isaac, H. M. Gun Carriage Manufactory, Madras, India: (or care of H. Tipping, Bridgewater Foundry, Patricroft, near Manchester.)
1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.
1863. Tomlinson, Edward, Miles Platting Works, Elm Street, Manchester.
1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.
1865. Toomey, Edward, Royal Phœnix Iron Works, Dublin.
1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway, Maryport.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1863. Townsend, William, West Orchard, Coventry.
1865. Trow, John James, Messrs. William Trow and Sons, Wednesbury.
1862. Troward, Charles, Great Northern Railway, Locomotive Department, Doncaster.
1859. Turner, Edwin, Bowling Iron Works, near Bradford, Yorkshire.
1866. Turner, Frederick, St. Peter's Iron Works, Ipswich.
1856. Tyler, Capt. Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, Engineer, Chartered Gas Works, 146 Goswell Street, London, E.C.
1865. Usher, George Moon, Beverley Iron Works, Beverley.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1856. Vernon, John, Iron Ship Building Yard, Brunswick Dock, Liverpool.
1865. Vickers, Albert, Don Steel Works, Sheffield.
1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1856. Waddington, Thomas, New Dock Iron Works, Leeds.
1865. Wainwright, William, Great Western Railway, Locomotive Department, Worcester.
1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
1864. Walker, Bernard Peard, Junction Cut Nail Works, Wolverhampton.
1861. Walker, John G., Netherton Iron Works, near Dudley.
1847. Walker, Thomas, Patent Shaft Works, Wednesbury.
1863. Walker, William Hugill, Wicker Iron Works, Sheffield.

1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Works, Liverpool.

1865. Waller, George Arthur, Messrs. Guinness, James' Gate, Dublin.

1865. Walpole, Thomas, Port of Dublin Ship Yard, Dublin.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Glover Street, Birmingham.

1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Burton Iron Works, Burton-on-Trent.

1862. Watkins, Richard, Canal Iron Works, Poplar, London, E.

1866. Watson, Robert, Engineer, Black Boy Collieries, Bishop Auckland.

1862. Webb, Francis William, Bolton Iron and Steel Works, Bolton.

1862. Webb, Henry Arthur, Bretwell Hall Iron Works, near Stourbridge.

1860. Weild, William, Tipping Street, Ardwick, Manchester.

1862. Wells, Charles, Moxley Iron Works, near Bilston.

1862. Westmacott, Percy G. B., Elswick Engine Works, Newcastle-on-Tyne.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.

1864. White, Isaiah, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly).

1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

1859. Whitham, Joseph, Perseverance Iron Works, Kirkstall Road, Leeds.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.

1847. Whitworth, Joseph, Chorlton Street, Manchester.

1859. Wickham, Henry Wickham, M.P., Low Moor Iron Works, near Bradford, Yorkshire.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.

1863. Wicksteed, Thomas, 8 Torquay Terrace, Headingley, near Leeds. (*Life Member.*)

1865. Williams, Edward, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1859. Williams, Richard Price, London Iron and Steel Works, East Greenwich, S.E.

1856. Wilson, Edward, Great Western Railway, Worcester.

1859. Wilson, George, Cyclops Steel and Iron Works, Sheffield.

1865. Wilson, James Edwards, Engineer, Indian Branch Railways, Cawnpore, India.

1863. Wilson, John Charles, East India House, 5 Lime Street, London, E.C.

1852. Wilson, Joseph W., 9 Buckingham Street, Strand, London, W.C.

1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.

1860. Wilson, William, 4 Victoria Street, Westminster, S.W.

1865. Winby, Clifford Etches, Atlas Iron Works, Cardiff.
1862. Winby, William Edward, Old Park Iron Works, Wednesbury.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1863. Wise, Francis, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1865. Woodall, Solomon, Windmill End Boiler Works, near Dudley.
1848. Woodhouse, Henry, London and North Western Railway, Stafford.
1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.
1858. Woods, Hamilton, Liver Foundry, Ordsal Lane, Salford, Manchester.
1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.
1866. Wray, William, Ship Building Yard, Burton Stather, near Brigg.
1866. Wren, Henry, London Road Iron Works, Manchester.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.
1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.
1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.
1865. Wyllie, Andrew, Vauxhall Foundry, Liverpool.
1853. Wymer, Francis W., Surveyor of Steam Vessels, Mercantile Marine Office, Dublin.

1861. Yule, William, 94 Cumberland Street, South Side, Glasgow.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Museum Building, Trinity College, Dublin.
1847. Fairbairn, William, LL.D., The Polygon, Ardwick, Manchester.

ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1848. Branson, George, Harborne Road, Edgbaston, Birmingham.
1864. Branson, Joseph W., Harborne Road, Edgbaston, Birmingham.
1863. Brockbank, William, 37 Princess Street, Manchester.
1866. Chadwick, William, Monkbridge Iron Works, Leeds.
1848. Crosby, Samuel, Tenby House, Victoria Road, Aston, Birmingham.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1863. Fairbairn, John, Newcastle Chare, Newcastle-on-Tyne.
1863. Fisher, John, Priory Street, Dudley.
1863. Forster, George Emmerson, Collingwood Chambers, Newcastle-on-Tyne.

1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1865. Hall, John, 56 King Street, Manchester.
1864. Hornblower, Joseph Wells, 14 Waterloo Street, Birmingham.
1860. Hutchinson, William, Blue Lias Lime Stone Offices, Lyme Regis.
1858. Lawton, Benjamin C., Benwell Grange, Newcastle-on-Tyne.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, 11 New Broad Street, London, E.C.
1860. Manby, Cordy, Tower Street, Dudley.
1863. Nichols, William, Midland Copper Works, Guild Street, Burton-on-Trent.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1856. Pettifor, Joseph, Midland Railway, Derby.
1864. Peyton, Abel, Oakhurst, Church Road, Edgbaston, Birmingham.
1861. Ratcliff, Charles, Wyddrington, Edgbaston, Birmingham.
1863. Rigg, Arthur, The College, Chester.
1866. Scott, John Peers, 10 Tib Lane, Cross Street, Manchester.
1859. Sherriff, Alexander Clunes, M.P., Great Western Railway, Worcester.
1863. Storey, Thomas R., 17 Gracechurch Street, London, E.C.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)
1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.
1865. Warden, Thomas, Lionel Street, Birmingham.
1848. Warden, William Marston, Edgbaston Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield.
1866. White, Richard Lewis, Great Western Railway, Swindon.
1862. Whitehead, William, Don Steel Works, Sheffield.
1865. Whitley, Joseph, Bowman Lane, Leeds.
1863. Woolley, John, Marehay Colliery, Ripley, near Derby.

GRADUATES.

1866. Butler, James, Atlas Works, Manchester.
1866. Butler, Thomas Snowden, Kirkstall Forge, Leeds.
1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1865. Hewett, Edward Edwards, Yorkshire Engine Co., Meadow Hall Works, near Sheffield.
1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.
1861. Middleton, Henry Charles, Vulcan Iron Foundry, Summer Lane, Birmingham.
1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.

PROCEEDINGS.

25 January, 1866.

The Nineteenth Anniversary Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 25th January, 1866; Robert Napier, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.

1866.

The Council have great pleasure, on the occasion of the Nineteenth Anniversary of the Institution, in congratulating the Members upon the very satisfactory position and the continued progress of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December 1865 shows a balance in the Treasurer's hands of £3474 3*s.* 10*d.* after the payment of the accounts due to that date. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1865, and report that the following Balance Sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The Council report with great satisfaction the large increase in the number of Members that has taken place during the last year; the total number of Members of all classes for the year being 652, of whom 15 are Life Members, 36 are Honorary Members, and 3 are Graduates, being an effective increase of 80 during the year.

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The following deceases of Members of the Institution have occurred during the last year 1865 :—

Henry Peet, ...	Wolverton.
William Keld Whytehead, . .	Paraguay.
Nicholas Wood, ...	Hetton.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year; and also of expressing their thanks to the Donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present copies of their Works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

Smithsonian Meteorological Observations from 1854 to 1859; from the Smithsonian Institution, Washington.

Annual Report of the Smithsonian Institution for 1863; from the Institution.

Statistics of the Foreign and Domestic Commerce of the United States for 1864; from the Smithsonian Institution.

The Iron Trade of Carinthia, by Joseph de Rosthorn; from the author.

[redacted]

Report of the British Association for the Advancement of Science; from the Association.
Transactions of the Society of Engineers; from the Society.
Transactions of the Institution of Engineers in Scotland; from the Institution.
Proceedings of the South Wales Institute of Engineers; from the Institute.
Journal of the Architect and Engineers' Society for the kingdom of Hannover; from the Society.
Journal of the Royal United Service Institution; from the Institution.
Proceedings of the Royal Institution of Great Britain; from the Institution.
Report of the Royal Cornwall Polytechnic Society; from the Society.
Report of the Midland Steam Boiler Association; from Mr. Edward B. Marten.
United States Patent Office Report; from the Commissioners.
Journal of the Board of Arts and Manufactures for Upper Canada; from the Board.
Journal of the Society of Arts; from the Society.
The Engineer; from the Editor.
The Mechanics' Magazine; from the Editor.
The Civil Engineer and Architect's Journal; from the Editor.
The London Journal of Arts; from the Editor.
The Artizan Journal; from the Editor.
The Practical Mechanic's Journal; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
The Steam Shipping Journal; from the Editor.
Specimen of Blenkinsop Rack Rail and Chairs; from Mr. Alexander Allan.
Specimens of improved Safety Valve for Steam Boilers; from Mr. William Naylor.
Specimens of Gunmetal and Wrought Iron Tuyeres; from Mr. N. Neal Solly and Mr. Thomas Holcroft.
Bust of the President, Robert Napier, Esq.; presented by Mr. Napier.

The Council have great satisfaction in referring to the number and character of the Papers that have been brought before the meetings during the past year, and the practical value and interest of the communications and the discussions that took place upon them, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of

executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended and other subjects advantageous to the Institution.

The following Papers have been read at the Meetings during the last year:—

On the relative advantages of the Inch and the Metre as the Standard Unit of Decimal Measure; by Mr. John Fernie, of Leeds.

On the application of Steam Power to Cultivation; by the late Mr. John Fowler, and Mr. David Greig, of Leeds.

Description of a High-Speed Compressed-Air Hammer, for Planishing, Stamping, Forging, &c.; by Mr. William D. Grimshaw, of Birmingham.

On Machinery employed in the Preparation and Spinning of Flax; by Mr. Thomas Greenwood, of Leeds.

Description of a Portable Steam Rivetter; by Mr. Andrew Wyllie, of Liverpool.

On the Manufacture of Compressed Peat Fuel; by Mr. Charles Hodgson, of Portarlington.

Description of the Bank-Note Printing Machine at the Bank of Ireland; by Mr. Thomas Grubb, of Dublin.

Description of a Rock Boring Machine; by Mr. George Low, of Dublin.

On the new Dublin Corporation Water Works for the supply of Water from the River Vartry; by Mr. Parke Neville, of Dublin.

On an improved Safety Valve for Steam Engine Boilers; by Mr. William Naylor, of London.

On an improved method of Taking Off the Waste Gas from Open-Topped Blast Furnaces; by Mr. George Addenbrooke, of Darlaston.

Description of a Gunmetal Tuyere for Blast Furnaces; by Mr. N. Neal Solly, of Willenhall.

The Council have particular pleasure in referring to the great success and interest of the Annual Meeting of the Institution that was held in Dublin last summer during the time of the Dublin International Exhibition, and in expressing their special thanks to the Local Committee, the authorities of the University of Dublin, and the Honorary Local Secretaries, Dr. Downing and Mr. G. Arthur Waller, for their excellent arrangements and the very handsome reception that was given to the Members of the Institution on that occasion; and also their thanks to the railway authorities for the special arrangements granted for the excursions. The

Council refer particularly to the great advantage afforded to the Members in the admirable opportunity provided them for visiting the important works of the Dublin Corporation Water Works, the Peat Works, Copper Works, and Lead Works; and they offer their acknowledgments to the authorities of the several works for the great facilities afforded to the Members for seeing the works and the handsome reception given to them on the occasion. The Council look forwards with confidence to the important advantages arising from the continuance of these Annual Meetings in different parts of the country, from the facilities afforded by them for the personal communication of the Members in different districts, and from the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The Council have had under consideration for some time the following modifications in the Rules respecting the qualification and titles of Members and the Meetings of the Institution &c., and now recommend them for adoption:—

That instead of the age for the admission of both Graduates and Members being the same, namely 21 years, the age for the admission of Graduates be 3 years earlier or 18 years, and that for Members be 3 years later or 24 years.

That instead of the title of Honorary Members now applied to subscribing honorary members, the title of Associates be adopted; and that the title of Honorary Members be restricted to cases of free membership specially presented by the Council.

That all communications to the Meetings are to be the property of the Institution, and to be published only by the authority of the Council.

That the four General Meetings of the Institution in each year be as follows:—three to be in Birmingham, on the fourth Thursday in the months of January, April, and October; and the fourth to be the Annual Meeting held in the summer in different localities to be arranged by the Council; the January Meeting to be the Anniversary Meeting for the annual election of officers.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present Meeting for the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

Steam Engine Boilers, particulars of construction—form and extent of heating surface—relative value of radiant surface and flue surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low pressure and high pressure—steel boilers—cast iron boilers—welded boilers—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—use of injector—circulation of water.

Steam Engines—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air pumps—governors—valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

Pumping Engines, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting

pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—details of pit work of pumping engines at mines.

BLAST ENGINES, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

MARINE ENGINES, power of engines in proportion to tonnage—different constructions of engines, double cylinder engines, trunk engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—governors and storm governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—consumption of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood and construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—distribution of weight on wheels.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

CALORIC ENGINES—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines,

construction and practical application, power obtained, comparative effect and economy.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

SUGAR MILLS, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

ROPE-MAKING MACHINERY—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, planing, rounding, and surfacing—copying machinery.

GLASS MACHINERY—manufacture of plate and sheet glass—construction of heating furnaces, annealing kilns, &c.—grinding and polishing machinery.

LATHES, PLANING, BORING, DRILLING, AND SLOTTING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolls.

STEAM HAMMERS, improvements in construction and application—friction hammers—air hammers.

RIVETTING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—comparative strength of drilled and punched plates—rivet-making machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

LOCKS, and lock-making machinery—iron safes.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

WATER PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

AIR PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

ROTARY AND CENTRIFUGAL PUMPS, ditto ditto ditto.

FIRE ENGINES, hand and steam, ditto ditto ditto.

SLUICES AND SLUICE COCKS, worked by hand or hydraulic power, ditto.

CRANES, steam cranes, hydraulic cranes, pneumatic cranes, travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—power transmitted—method of moulding—strength of iron and wood teeth.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping

ships' bottoms clean—galvanic action, nature, and preventives.

Alloys of Metals, facts relating to different alloys.

Friction of Various Bodies, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

Iron Roofs, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast iron, wrought iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

Fire-proof Buildings, particulars of construction—most efficient plan—results of trials.

Chimney Stacks of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

Bricks, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry clay bricks—machines for brick making—burning of bricks.

Gas Works, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure.

Water Works, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—water meters, construction and working.

Well Sinking, and Artesian Wells, facts relating to—boring tools, construction and mode of using.

Tunnelling Machines, particulars of construction, and results of working.

Coffer Dams and Piling, facts relating to construction—cast iron sheet piling.

Piers, fixed and floating, and pontoons, ditto ditto.

Pile Driving Apparatus, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles.

Dredging Machines, particulars of improvements—application of dredging machines—power required and work done.

Diving Bells and Diving Dresses, facts relating to the best construction.

Lighthouses, cast iron and wrought iron, ditto ditto.

Ships, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire rope rigging—comparative strength and advantage of iron and wood ships.

Guns, cast iron, wrought iron, and steel—manufacture and proof—rifling—manufacture of shot and shells.

Mining Operations, facts relating to mining—modes of working and proportionate yield—coal cutting machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas— ainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—stone breaking machines—mode of breaking, pulverising, and sifting various descriptions of ores.

Blasting, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

Blast Furnaces, shape and size—consumption of fuel—burden, make, and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot blast ovens—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace and mode of charging.

Puddling Furnaces, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

Heating Furnaces, best construction—consumption of fuel, and heat obtained.

Converting Furnaces, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

Smiths' Forges, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

Smiths' Fans and Fans generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains—mechanical ventilation and warming of public buildings.

Coke and Charcoal, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

Railways, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection,

deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

Switches and Crossings, particulars of improvements, and results of working.

Turntables, particulars of various constructions and improvements—engine turntables.

Signals for stations and trains, and self-acting signals.

Electric Telegraphs, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying.

Railway Carriages and Wagons, details of construction—proportion of dead weight.

Breaks for carriages and wagons, best construction—self-acting breaks—continuous breaks.

Buffers for carriages, &c., and station buffers—different constructions and materials.

Couplings for carriages and wagons—safety couplings.

Springs for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

Railway Wheels, wrought iron, cast iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought iron wheels.

Railway Axles, best description, form, material, and mode of manufacture.

The Papers are to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left side. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31st December, 1865.

Cr.	£	s.	d.
By Balance 31st December, 1864	2901	19	5
,, Subscriptions from 17 Members in arrear	51	0	0
,, ditto from 1 Graduate in arrear	2	0	0
,, ditto from 568 Members for 1865	1704	0	0
,, ditto from 2 Graduates for 1865	4	0	0
,, ditto from 3 Members in advance for 1866	9	0	0
,, ditto from 1 Life Member	30	0	0
,, Entrance Fees from 95 New Members	190	0	0
,, ditto from 1 New Graduate	1	0	0
,, Sale of Extra Reports	27	2	0
,, Interest from Bank	122	7	6
	£5042	8	11

Dr.				£	s.	d.
To Printing and Engraving Reports of Proceedings	688	0	6			
Less Authors' copies of papers, repaid	37	3	6	650	17	0
,, Stationery and Printing				69	5	6
,, Office Expenses and Petty Disbursements				73	8	7
,, Coals, Gas, and Water				17	10	9
,, Expenses of Meetings				54	12	11
,, Fittings and Repairs				3	0	11
,, Travelling Expenses				42	7	0
,, Parcels				4	19	5
,, Postages				78	13	6
,, Salaries				450	0	0
,, Insurance				3	10	9
,, Rent and Taxes				119	18	9
Balance 31st December, 1865				3474	3	10
				£5042	8	11

(Signed) EDWARD JONES, WALTER MAY, } Finance Committee.

25th January, 1866.

MEMOIRS

OF MEMBERS DECEASED IN 1865.

HENRY PEET was born at Wigan in 1813; and after serving his time under Messrs. Thompson and Cole, engineers and millwrights, at Bolton, he had charge of the engine station of the London and North Western Railway at Preston, until his appointment in 1857 as locomotive superintendent of the Lancaster and Carlisle Railway. Subsequently, on the amalgamation of this line with the London and North Western Railway in 1862, he became manager of the locomotive works at Wolverton. He was elected a Member of the Institution in 1859, and died at Wolverton after an illness of six months on 10th February 1865, in the fifty-third year of his age.

WILLIAM H. KELD WHYTEHEAD was born in London in 1825; and after serving his apprenticeship to Messrs. J. and A. Blyth of Limehouse, he was for some years the editor of the "Artizan." In 1854 he was appointed engineer-in-chief to the Government of Paraguay, and continued to occupy that post up to the time of his death. The arsenal at Assumption, the capital of Paraguay, was organised by him; and with the assistance of a staff of English workmen and English tools he executed many other important works, and kept in efficient order a considerable fleet of steam vessels. His services were highly valued by the Government of Paraguay, but his health having been for nearly three years in a weak state, the additional labour and anxiety thrown upon him, in consequence of the war between Paraguay and Brazil, proved too much for his strength, and he died at Assumption on the 13th July 1865 at the age of forty. He was elected a Member of the Institution in 1852.

Nicholas Wood, of Hetton Hall in the county of Durham, was born on 24th April 1795, at Ryton, Durham; and was sent by Sir Thomas Liddell of Ravensworth to the Killingworth Colliery to learn the profession of colliery viewer. Here he became acquainted with the late George Stephenson, and was associated with him in his inventions and experiments in connection with the Safety Lamp and the Locomotive Engine; and although he continued his profession of mining engineer, he was also intimately connected with the progress of the locomotive and railways. In 1822 he entered into a discussion of the superiority of locomotives over stationary engines for working railroads; and in 1825 he published a practical treatise on railroads, giving the results of extensive and important experiments on the subject. In 1829 he was appointed one of the judges to award the premium offered by the Liverpool and Manchester Railway for the best locomotive engine. In 1845 he was engaged in the battle of the gauges, being in favour of the narrow gauge; and he was also connected with various railways as engineer and as a director. Mr. Wood occupied a leading position in his profession of mining engineer, and held many important appointments, being the mineral adviser to the Durham Bishopric Estates and to Lord Ravensworth, and also manager of the Hetton and many other collieries; and he was frequently consulted on mining matters by Government. During the latter portion of his life he confined his attention more particularly to those mining affairs in which he himself held so large an interest. He was elected a Member of this Institution in 1858, and contributed a valuable paper on the improvements and progress in the working and ventilation of coal mines in the Newcastle-on-Tyne district within the last fifty years. He died in London on 19th December 1865 at the age of seventy.

The CHAIRMAN moved that the Report of the Council be received and adopted, which was passed.

The several modifications in the Rules of the Institution, recommended in the Report of the Council, were then moved by the Chairman, and were passed.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following Officers and Members of Council were found to be duly elected for the ensuing year:—

PRESIDENT.

JOSEPH WHITWORTH, . . .	Manchester.

VICE-PRESIDENTS.

CHARLES F. BEYER, . . .	Manchester.
WILLIAM CLAY, ...	Liverpool.
ROBERT HAWTHORN, . . .	Newcastle-on-Tyne.
SAMPSON LLOYD, ...	Wednesbury.
HENRY MAUDSLAY, . . .	London.
JOHN RAMSBOTTOM, . . .	Crewe.

COUNCIL.

JOHN FERNIE, ...	Leeds.
SIR CHARLES FOX, . . .	London.
EDWARD HUMPHRYS, . . .	London.
WALTER MAY, ...	Birmingham.
JOHN ROBINSON, . . .	Manchester.

PAST-PRESIDENTS.

Ex officio permanent Members of Council.

SIR WILLIAM G. ARMSTRONG, .	Newcastle-on-Tyne.
WILLIAM FAIRBAIRN, . . .	Manchester.
JAMES KENNEDY, ...	Liverpool.
ROBERT NAPIER, . . .	Glasgow.
JOHN PENN, ...	London.

COUNCIL.

Members of Council remaining in office.

John Anderson, ...	Woolwich.
Frederick J. Bramwell, . .	London.
Charles Cochrane, ...	Dudley.
Edward A. Cowper, . . .	London.
George Harrison, ...	Birkenhead.
Edward Jones, ...	Wednesbury.
W. Montgomerie Neilson, .	Glasgow.
C. William Siemens, . . .	London.
Charles P. Stewart, . .	Manchester.
John Vernon, ...	Liverpool.

TREASURER.

Henry Edmunds, . . .	Birmingham.

SECRETARY.

William P. Marshall, . .	Birmingham.

The following New Members were also elected:—

MEMBERS.

Charles James Brown, . .	Birmingham.
William Bryham, ...	Wigan.
Thomas Claridge, . . .	Bilston.
Ephraim Death, ...	Leicester.
George Fowler, . . .	Ashby-de-la-Zouch.
George Gilroy, ...	Wigan.
Edwin James Grice, . .	Westbromwich.
Charles Frederick Gurden, .	Birkenhead.
John Hardy, ...	Armagh.
Thomas Ridley Hetherington, .	Manchester.
John Satchell Hopkins, . .	Birmingham.
John Kershaw, . . .	London.
Conrad Knap, ...	Birmingham.

Albert Lewis Newdigate, . .	Shrewsbury.
Thomas Parton, . . .	Darlaston.
Arthur John Peele, . . .	Shrewsbury.
Frederic Cornell Reynolds, .	London.
Thomas Rose, ...	Bilston.
Joseph De Rosthorn, . :	Vienna.
Frank Shaw, ...	Burton-on-Trent.
Fereday Smith, . . .	Manchester.
Thomas Whitwell, . . .	Stockton-on-Tees.

ASSOCIATES.

William Chadwick, . . .	Leeds.
John Peers Scott, . . .	Manchester.

The following paper was then read :—

DESCRIPTION OF AN IMPROVED CHRONOMETRIC GOVERNOR FOR STEAM ENGINES, &c.

By Mr. C. WILLIAM SIEMENS, of London.

The Chronometric Governor has already formed the subject of a paper read by the author at a former meeting of this Institution (see Proceedings Inst. M. E. 1853 page 75). It consisted in its original form of a conical pendulum, freely suspended from a universal (ball and socket) joint (see Plate 17, 1853), which was maintained in motion by a force that was independent of the engine, although constantly replenished by it; and the pendulum was therefore at liberty to rotate with a uniform velocity. A differential motion between the conical pendulum and the engine to be governed was obtained by means of a mechanical arrangement, whereby, so long as the engine continued to rotate with precisely the same velocity as the pendulum, the throttle-valve would not change its position; whereas the smallest acceleration or retardation of the engine would forthwith close or open the valve to the requisite extent, for re-establishing the equilibrium between the power and the resistance, at the speed that is prescribed absolutely by the fixed speed of the pendulum. In order to obtain uniform rotation of the pendulum, it was necessary that its angle of rotation should be maintained constant, notwithstanding the variations in the amount of its driving power that resulted from the resistance of the throttle-valve, which had to be overcome by the inertia of the pendulum at each time that a re-adjustment between the power and the load of the engine was required. This was effected by increasing on the one hand the maintaining power of the pendulum beyond what was requisite under ordinary circumstances, in order to guard against an occasional deficiency of power; and by calling into existence on the other hand an extraneous resistance by a friction break, whenever the pendulum reached its full angle of rotation, in order to prevent its further acceleration.

A considerable number of steam-engine governors were constructed by the writer in accordance with this description in the years 1844-47, which continue to work in a highly satisfactory manner up to the present day, in all cases where sufficient attention has been bestowed upon them. They continue also to be used by the Astronomer Royal for regulating the motion of telescopes and chronographical apparatus with almost mathematical precision. Notwithstanding these results however, the chronometric governor has not received an extended application, owing to its comparative costliness and the delicacy of its working parts, which require frequent attention to keep them in perfect order. The writer's early attempts to reduce this governor into a form more suited for common use were not attended with success, inasmuch as the accuracy of the instrument was found to be sacrificed in a great measure; and the endeavours of others in the same direction do not seem to have proved more satisfactory. But last year an idea occurred to the writer, which appeared calculated to furnish uniform rotation under varying circumstances of driving power, without having recourse to so delicate an instrument as the free conical pendulum; and this idea has given rise to the governor which forms the subject of the present paper.

If an open cylindrical vessel, such as a glass tumbler or cup, containing a certain quantity of water, is made to rotate upon its vertical axis, as shown in the diagram, Fig. 2, Plate 1, the water

[redacted]

whence it follows that, when the speed is already sufficient to raise the liquid to the edge of the cup, a small increase of speed will produce a very decided overflow of liquid. The quantity of liquid within the cup being limited, a rise at the circumference is accompanied by a depression of the centre; and this has been taken advantage of by Mr. Ramsbottom to devise a measure of rotary velocity, (see Proceedings Inst. M. E. 1861 page 49).

The present object is not to measure velocity, but to maintain a constant predetermined velocity in steam engines and other more delicate mechanism; and for this purpose the principles of liquid gyration above referred to have been taken advantage of by the writer in the following manner.

The improved Chronometric or Gyrometric Governor for Steam Engines is shown in Figs. 3 to 7, Plates 1 to 4. It consists of an open cup A of parabolic shape, Figs. 4 and 5, fixed upon a vertical spindle B, and caused to revolve within the closed chamber C containing the liquid, the bottom of the cup being open and always immersed below the surface of the liquid. When the cup is made to revolve rapidly, the liquid contained in it rises round the sides of the cup and sinks in the centre, the surface of the liquid assuming the inverted parabolic form shown in Fig. 5; and on reaching the edge of the cup it overflows into the surrounding chamber, while at the same time a fresh supply of liquid is drawn into the cup through the opening in the bottom: and the power absorbed in putting the overflowing liquid into motion offers a continuous resistance to the rotation of the cup. On a level with the edge of the cup, a series of twelve to sixteen fixed vanes D are placed round the circumference of the external chamber C, and a corresponding set of blades E are also fixed round the outside of the cup just below the rim; so that the sheet of liquid overflowing from the edge of the revolving cup is thrown against the vanes D, and by these is thrown back against the blades E on the cup, whereby the overflowing liquid is made to offer an additional resistance to the rotation of the cup. A second series of vanes and blades can also be added below if desired, for still further increasing the resistance, and thereby increasing the

power of the revolving cup as a governor of speed. The internal radial arms uniting the shell of the cup A to the centre boss, as shown in Fig. 6, serve to communicate the rotary motion to the liquid inside the cup; while the bottom of the external chamber C is provided with a number of radial ribs, as shown in Fig. 5, for the purpose of checking rotary motion in the liquid outside the cup.

So long as the cup is driven at a constant speed, the overflow is constant, and produces an absolutely constant resistance; and hence, if the cup be driven by a constant driving power, independent of the engine, its speed is as uniform as that of a chronometer, within a very small margin of variation which is definitely fixed; and it continues revolving at an unchanging speed, totally independent of the engine, and consequently affords the means of forming a governor for controlling the speed of the engine to a constantly uniform rate. The constant power for driving the cup is obtained by the weight F, Fig. 4, on the lever of the throttle-valve spindle G, which is connected with the spindle of the cup A and also with the main driving shaft H of the engine, through a set of differential wheels and a rocking frame turning loose upon the spindle of the cup. The main driving shaft H of the engine drives the vertical shaft K, which carries the inverted wheel L; and on the bottom of the spindle B of the regulating cup, which is in a line with the shaft K, is fixed the pinion J, the diameter of which

engine is in the opposite direction, and is constantly tending to raise or wind up the weight.

The result therefore is that, when the engine is running at exactly the same speed as the governor, so that the wheel L makes exactly one revolution during the time that the governor allows the pinion J to make four revolutions, the rocking frame M remains stationary, holding the throttle-valve constantly in one position, and the weight F neither rises nor falls. But whenever the speed of the engine exceeds or falls short of the proper rate, by even the slightest variation, the differential action of the wheels is instantly called into play, and causes the rocking frame to be shifted in position in the direction of the relatively faster wheel, and thereby closes or opens the throttle-valve to a sufficient extent to bring back the engine at once to the proper rate fixed by the governor. The engine is therefore compelled to run with the same regularity of speed as the governor, while the regularity of the governor is ensured by the driving power being derived from the constant weight, which will always remain in free suspension; because before reaching its lower stop in falling, the whole of the steam would be turned on and would accelerate the engine to raise it; and before reaching its upper stop in rising, the supply of steam would be so much reduced as to retard the engine, even if all its work were thrown off, and give the preponderance of power to the weight.

The important difference in principle of action between the new chronometric governor and the ordinary steam-engine governors at present in general use lies in the fact that the ordinary governors regulate the speed to a uniform standard rate only under the special conditions of work for which they are adjusted, and whenever those conditions are altered the standard of speed becomes altered also. Thus an engine having the full amount of work put upon it, and governed by an ordinary ball governor, will be kept to a uniform speed by the governor so long as the average resistance to be overcome by the engine continues the same; but whenever any of the work is taken off, the speed of the engine will

be increased to a higher rate corresponding to the diminished resistance, and at this higher rate the speed will then be kept uniform by the governor so long as the diminished resistance continues without further alteration. This arises from the circumstance that the degree of opening of the throttle-valve is directly controlled by the angle to which the governor balls are raised by the velocity of their revolution, the throttle-valve being moved only by a change in the angle of suspension of these balls; whence it follows that a larger supply of steam for overcoming any increase of work can be obtained only in conjunction with a smaller angle of the governor balls, and consequently with a lower speed; and that a larger angle of the governor balls and consequently a higher speed must be attained, in order to reduce the supply of steam for meeting any reduction in the work done by the engine. In the chronometric governor on the contrary, it will be seen that the governor is not driven by the engine itself, as is the case in the ordinary ball governors, but by the constant weight on the throttle-valve lever, whereby a constant speed of the governor is ensured; and the slightest deviation of the engine from this fixed speed causes the throttle-valve to be either opened or closed to the extent requisite for bringing back the engine to that same rate. Thus the degree of opening of the throttle-valve and the consequent supply of steam to the engine are altogether independent of the speed of either the engine or the governor; and the quantity of steam supplied to the engine is always exactly equivalent to the quantity of work to be performed, while the speed of the engine is maintained unchangeably the same, to whatever extent the work upon it may be diminished or increased within the limit of work which the engine is capable of doing with its full supply of steam.

It will be shown in the subsequent portion of the present paper that, when water is the liquid employed in the governor, a cup of 6 inches diameter and 6 inches height of rim above the water level, without external blades, is capable of absorbing 0·004 horse power without suffering an increase of speed exceeding 2 per cent.; but it is shown by experiment that the addition of the external blades E round the cup and the set of fixed vanes D in the external chamber,

Figs. 5 and 6, increases the power of the cup to 0·007 horse power, without any greater increase of speed. Assuming that the work required to be performed by such a governor consists in moving a throttle-valve through a range of 6 inches (0·5 foot) in 5 seconds (0·083 minute), then the power of the governor is sufficient to overcome a resistance at the throttle-valve of

$$\frac{0{\cdot}007 \times 0{\cdot}083 \times 33000}{0{\cdot}5} = 38{\cdot}35 \text{ lbs.}$$

and it is evident that a resistance of 38 lbs. far exceeds what may reasonably be expected of a regulating valve. It must be observed that the increase of speed due to the development of this amount of force ceases as soon as the work is accomplished, or in a few seconds of time; after which the cup and with it the engine will resume the normal rate. The governor shown in Figs. 5 and 6 has a cup 8 inches diameter, which would be capable of overcoming a still greater resistance.

If it is desired, instead of moving a simple throttle-valve, that the governor should act upon a variable expansion valve, or even upon the sluice of a waterwheel, requiring considerable power to move it, the rocking frame may be arranged as a pulley or wheel, and may be connected to the work in such a manner that several of its own revolutions are required to accomplish the necessary action, thereby gaining power at the expense of time.

The liquid that is employed in this governor is either water or paraffin oil; and the chamber C, Fig. 5, containing the liquid and revolving cup, is virtually closed, so that no loss from evaporation takes place. The absolute speed of the governor is determined by simply changing the total quantity of liquid in the chamber C, the level being shown by the gauge glass O at the side of the chamber, Fig. 3, which is graduated for the different speeds. The liquid is filled in when required through the closed hole P in the cover of the chamber, which serves also for supplying oil occasionally into the lubricating cup upon the top of the spindle B.

One of these governors, working with water, and having a cup of 6 inches diameter and 6 inches height, has now been in constant operation for several months at the writer's telegraph works at Woolwich, employed in regulating a high-pressure engine running

at high speed with very variable load, over which the ordinary ball governor previously used had so little control that the engineman was obliged to regulate the speed continually by the hand stop-valve. The new governor maintains the engine at an exceedingly uniform speed, under the most extreme variations of load; and no trouble of any kind has been experienced in its working.

In the new governor it will be observed that all the parts are readily accessible. The two vertical spindles B and K, Fig. 5, rotate in complete balance, and are therefore not liable to wear sideways. This governor is also equally applicable on board ship, as a vertical position of the revolving cup of liquid is by no means necessary. These are decided advantages in favour of the new governor over the former chronometric governor, the principle of this governor having already been approved by many mechanical engineers.

The principle of the revolving cup of liquid has also been applied in a more delicate and an absolutely chronometric form, as shown in Fig. 1, Plate 1, for regulating clockwork and telegraph apparatus, where the variations of speed to which the machinery is exposed are not by any means either so sudden or so large in amount as in the case of a steam engine. The cup A is mounted upon a spindle B driven direct by the clockwork or apparatus that is required to be governed chronometrically; but instead of being fixed on the spindle, the boss of the cup runs free upon a quick double-threaded screw formed on the spindle, and the driving power to make the cup revolve with the spindle is conveyed through a spiral spring S, attached to the spindle and cup, which also supports the weight of the cup and liquid when running at the normal speed and with the proper amount of overflow. The result of this arrangement is that the depth of immersion of the cup in the liquid is self-adjusting; whereby any tendency to change of speed, arising from the slightest change of driving power, is instantly compensated by a corresponding change in the resistance to rotation, while the absolute speed of the cup continues constant without any alteration.

The chronometric correctness of the governor in this more delicate and perfect form will be understood from the following consideration of the principles of its action.

The velocity due to the height of the rim of the revolving cup above the level of the liquid in the external chamber is $\sqrt{2\,g\,h}$, where h is the height in feet, and g is the acceleration (32 feet) produced by gravity after one second. In order therefore that the liquid may be raised so as to overflow from the rim of the cup, it must have this velocity communicated to it. The actual velocity of the overflowing liquid is the same as the tangential velocity of the rim of the cup, or $n \times c$, where n is the number of revolutions of the cup per second, and c is the circumference of the rim of the cup in feet. Hence the relation obtained for determining the speed at which a cup of given dimensions must rotate at the moment of overflow is

$$n\,c = \sqrt{2\,g\,h} \quad \text{or} \quad n = \frac{1}{c}\sqrt{2\,g\,h}.$$

It will be observed that the specific gravity of the liquid employed does not appear at all in this formula; for the only forces acting upon the liquid in the cup are gravity, which is constant, and the centrifugal force, which results solely from the velocity of rotation of the cup, and is therefore the same for all liquids, independent of their density. Hence the density of the liquid is immaterial as regards the velocity of the cup, and affects only the driving power required to maintain the cup at that velocity.

Applying the above formula to a cup of 6 ins. diameter or 1·57 ft. circumference, the height of rim above the level of the liquid being 6 ins. or 0·5 ft., the expression becomes $n = \frac{1}{1{\cdot}57} \times \sqrt{2 \times 32 \times 0{\cdot}5}$ $= 3{\cdot}6$ revolutions per second; or 216 revolutions per minute must be the speed of the cup in order to maintain the liquid up to the point of overflow. The same formula also serves to determine either the diameter or the height of cup that is required to produce a given speed of revolution.

The above calculation extends at present only to the moment when overflow would commence, showing the speed at which the given cup must revolve for maintaining the liquid up to the point of overflow. The increase of speed necessary for producing an

actual overflow, and the quantity of driving power absorbed by the overflowing liquid, upon the mutual relation of which depends the practical efficiency of the governor as a chronometric regulator of speed, are readily ascertained in the following manner for any given amount of overflow.

Taking the same cup of 6 inches diameter, and assuming that the amount of overflow is 60 cubic inches per second, and that the liquid employed is water, then, the area of inlet at the open bottom of the cup being 5 square inches, the water must rush into the bottom of the cup with a velocity of 1 foot per second. In order to obtain this rapidity of flow into the cup, the apex of the liquid paraboloid or the lowest water level inside the cup must be depressed below the water level in the external chamber to the extent of the height due to a velocity of 1 foot per second ($h = \frac{1}{64} v^2$) or $\frac{1}{64} \times 1^2 = \frac{1}{64}$ foot $= 0{\cdot}19$ inch. Moreover the circumference of the 6 inch cup being 1·57 feet while its speed is 3·6 revolutions per second, the velocity of the overflowing sheet of water is $1{\cdot}57 \times 3{\cdot}6 = 5{\cdot}65$ feet per second; and therefore a height of 0·05 inch is required above the rim of the cup, in order to provide the necessary area for the overflow of 60 cubic inches per second. Hence the result of the overflow is that the effective height of the cup is increased altogether from 6 inches to 6·24 inches; and therefore the previous velocity of the cup, 216 revolutions per [redacted]

Although an increase in velocity of only 2 per cent., for producing the overflow requisite to absorb so considerable an amount of surplus driving power as 1-250th horse power, may not appear of much importance in the ordinary purposes for which governors are employed, considering that this irregularity applies only to the short interval of a few seconds and is moreover reduced in amount by the addition of external blades round the cup as before described, yet it is evident that in order to obtain exceedingly uniform rotation with variable driving power something more than the simple cup is still required. It accordingly occurred to the writer that, if by some automatic arrangement the cup could be depressed into the liquid in the precise measure of the increase of resistance caused by the overflow, then the height to which the liquid would have to be raised would remain actually the same as it was before, and the time of rotation of the cup would therefore remain the same also.

This adjustment is accordingly effected in the delicate chronometric governor shown in Fig. 1 by the introduction of the spiral spring S for connecting the cup A to the driving spindle B, the upper end of the spring being fastened to the spindle and the lower end to the centre boss of the cup, while this boss fits upon a quick double-threaded screw on the driving spindle. The vertical tension of the spring supports the weight of the cup itself and of the liquid contained in it when at the point of overflow; but it is without any torsional tension until the moment that the liquid begins to overflow. The increase of driving power which produces the overflow produces also a corresponding torsion of the spring, and consequently a corresponding depression of the cup upon the screw threads, the direction of the rotation being arranged to suit the screw; and if the torsion of the spring be so adjusted that the requisite amount of depression of the cup is effected for a given limit in the increase of driving power, then the depression for any intermediate increase will also be just sufficient to correct the error of speed, and absolutely uniform rotation between those limits of driving power will be the result.

In order to test the accuracy of these views the writer has constructed the electric clock now exhibited, in which the cup of uniform rotation takes the place of the ordinary pendulum. The driving power is derived from a small "Marie Davy" or "Daniell" battery contained within the pedestal, which requires no further attention beyond being refilled with protosulphate of mercury at long intervals. The vertical driving spindle which carries the governor cup receives motion from an electro-magnet contained within the clock, where are also reducing wheels for communicating the motion from the spindle to the hands upon the dial, and a contact arrangement whereby the electric current is alternately broken and re-established in the coil in order to obtain the rotary motion. The bottom end of the driving spindle rests on an adjustable screw, as shown at T in Fig. 1, by which the regulating cup may be raised or lowered during its action, in order to effect the adjustment of the clock, which could not be accomplished to so great a nicety or with such facility by any adjustment of the strength of the spiral spring S that supports the cup. The liquid employed in this instance is paraffin oil, which is particularly applicable for the purpose on account of its high fluidity and its neutrality in a chemical point of view.

A peculiar feature of this clock, as with the steam-engine governor already described, is that it may be tipped on one side very considerably without producing any visible change in the

The cup of absolutely uniform rotation, with self-adjusting dip, as now described and shown in the electric clock exhibited, was the first form in which the writer embodied the idea of a revolving cup of liquid as a governor of speed. In applying this governor to a steam engine, it is evident that, if the power and the load upon the engine varied only between narrow limits, it might be possible to construct a cup of uniform rotation large enough to absorb directly all surplus power whenever it occurred, exactly the same as in the clock and other delicate machinery. But considering the actual extent of the variations in the case of a steam engine, and the importance of not sacrificing engine power, as would be the case if all surplus power were absorbed by the governor, it was necessary to seek for some means of giving the governor indirect command over the engine; and this is therefore accomplished by the use of the differential motion, and the rocking frame connected to the throttle-valve or expansion valve. At the same time the self-adjusting dip of the cup is dispensed with, the cup being no longer carried upon the driving shaft, but on a separate spindle driven independently by the constant weight; and the cup itself is made heavy, in order to increase its stability of rotation and to obtain in it a store of accumulated force, ready at any moment to act upon the throttle-valve of the engine. It has also been seen that the addition of the external blades round the rim of the cup nearly doubles its power as a governor.

The writer's practical career having commenced twenty-three years ago with the subject of the chronometric governor, although his attention has since been engrossed with other subjects, he trusts that this application of a new principle of action may lead to a more complete realisation of the object in view, namely the attainment of really uniform rotation in mechanism.

Mr. SIEMENS exhibited the regulating cup and differential wheels which had been at work in the governor employed to regulate the engine at his works at Woolwich; he also showed in work an electric clock regulated by the more delicate modification of the governor designed for that purpose.

The CHAIRMAN enquired whether in the application of the governor to marine engines the pitching of the vessel would in any way interfere with the action of the governor, as the cup containing the liquid would then be canted out of its upright position.

Mr. SIEMENS replied that the tilting of the governor into an inclined position did not interfere with its action, as was shown by tilting the clock now exhibited, when it was seen that the speed of the governor continued as regular as when it was standing upright and steady. This was in consequence of the revolving cup being made to dip into the liquid in the centre of the external chamber; so that however the governor might be tilted about, within all ordinary limits that could be met with in practice, the bottom of the cup would still remain submerged in the liquid, as the centre of the liquid would be exposed to comparatively little alteration in level. The utmost that could happen would be that the open bottom of the cup would become uncovered for an instant; but that would have no perceptible effect on the governor, as it would immediately afterwards be covered again, and the liquid would again rise up inside the cup by the centrifugal force. The rotation of the governor

modified form of the governor would be very useful for many purposes; for although with a steam-engine governor it was not necessary to attain anything like the regularity of a clock, yet there were many other applications of the governor where a very high degree of regularity was required, especially in telegraphic and astronomical apparatus, and it was more particularly with a view to these that he had constructed the more delicate modification of the governor as applied to the clock now exhibited.

The earlier form of the chronometric governor with the conical pendulum had been designed by himself several years previously, but was open to the great objection of being complex and rather delicate; and having lately taken up the subject again, he had been led to the improved construction now described, the action of which was exceedingly quick on the slightest alteration of speed in the engine, having a considerable advantage in this respect over the earlier governor, so that an engine could now be kept working with remarkable regularity.

The CHAIRMAN enquired whether the delicate governor now exhibited at work in connection with the electric clock was capable of showing the effect of any sudden alteration in the resistance to the driving power of the clock.

Mr. SIEMENS showed that the slight increase of friction produced by the pressure of a finger upon the driving spindle caused the cup of the governor to rise out of the liquid so that the overflow diminished, and ceased altogether if the friction were sufficiently increased; but the speed of the governor remained precisely the same as before, the increased power absorbed by the friction being compensated by the diminished resistance offered by the revolving cup of the governor. On removing the friction from the driving spindle the cup again sank to the proper depth in the liquid, and the overflow began again, while the speed still remained unaltered.

The CHAIRMAN enquired whether the action of the governor as applied to steam engines would be sufficiently prompt in the case of marine engines to check the engine at once, supposing the pitching of the vessel caused the screw ever to be raised out of the water altogether, as not unfrequently happened in a rough sea.

Mr. SIEMENS thought the action of the governor would be quite quick enough to meet such a case; for he had found the governor regulating the engine at his own works acted so promptly that even if the whole work was suddenly thrown off the engine no visible effect was produced on the speed of the flywheel.

The CHAIRMAN enquired what size of revolving cup would be required for the governor of an engine of large power; he supposed the size would be considerable for an engine of 1000 horse power.

Mr. SIEMENS thought that for an engine of 1000 horse power the cup of the governor would not have to be more than 15 inches diameter at the very utmost; and probably a 12 inch cup would be found quite sufficient.

Mr. E. A. COWPER said he had seen the governor at work upon the engine at Mr. Siemens' works at Woolwich, and had made an experiment to test its quickness of action in controlling the speed of the engine. A heavy plank of wood was applied as a lever against the rim of the flywheel, so as to act as a break, and the outer end was weighed down until the engine had just as much work upon it as the steam was capable of doing when the throttle-valve was full open. The break was then suddenly released altogether, so that the whole work was suddenly thrown off the engine, yet there was not the slightest difference to be perceived in the speed of the engine; and this appeared so surprising that he had repeated the experiment several times, but with the same result in each case. This was

tunity of judging of the efficiency of the principle of the governor from having employed a modification of the former chronometric governor for the purpose of regulating the speed of an engine driving rolls for rolling iron; and he had found that in this case the action of the governor was perfectly satisfactory, as the only difference observable when the work was thrown on the engine by a very heavy piece of iron passing through the rolls was that an increased volume of steam issued from the exhaust pipe, the speed of the rolls remaining unaffected. The efficiency of the governor in that case had proved so complete that he had since put up another to control an engine having the most irregular work to perform, and this second governor had also worked very well indeed. In that form of the governor however there was no doubt that the uniformity of its action was somewhat dependent upon the constancy of the friction, and some attention was therefore required to ensure the friction being maintained always the same. But the improved construction of governor now described, having the revolving cup of liquid substituted for the conical pendulum, required no attention to ensure its efficient working, as its action did not depend upon delicacy of adjustment nor uniformity of lubrication of surface, and therefore it was not liable to get out of order. The application of the governor to the electric clock now exhibited might perhaps lead to the notion that it was only suitable for such applications, and was too delicate for use as a steam-engine governor; but this extreme test of application to a clock only served to show the complete correctness of the principle, and did not in any way prove that the governor was unfitted to control an engine. The fact was that in the extent of its applicability the governor was as universal as the steam hammer, which would forge a large mass of iron or only crack a watch-glass. The governor could accordingly be used either as an absolute measurer of time for the most delicate chronometric purposes, according to the more refined mode of construction (shown in Fig. 1), with the revolving cup arranged to rise or fall upon the driving spindle; or if constructed according to the simpler plan (shown in Figs. 3 to 5), for use as a steam-engine governor, it still secured practical regularity of motion,

the action being instantaneous upon the slightest alteration of the load.

As an illustration of the way in which the speed of the governor was independent of the gravity of the liquid employed might be named the fact that, if a water wheel were to be turned by a stream issuing from a cistern having a given constant head, the speed of the wheel would clearly be the same whether water or mercury were used, although the power would be much less in the former case than in the latter. Similarly the speed of the governor was not affected by the specific gravity of the liquid employed in the revolving cup, but its power might be augmented without altering its size by increasing the specific gravity of the liquid; and the difference in the specific gravities of mercury, water, paraffin oil, and spirits of wine, afforded therefore an ample range for varying the power of the governor according to the amount of resistance which it had to overcome in working the throttle-valve of the engine. It had been shown in the paper that the power of the governor now exhibited, having a cup of 6 inches diameter and working with water, would be sufficient to move a resistance of 38 lbs. through 6 inches in 5 seconds, with an increase of speed in the governor itself of only about 2 per cent.; and as it was only during the time occupied by the governor in acting upon the throttle-valve that any change could take place in the speed of the engine, it followed that in the case of an engine running at 60 revolutions per minute and regulated

required by it when in action was less than half that taken up by the ordinary ball governor when the arms were opened out by its revolution.

Mr. W. Fairbairn considered the chronometric governor was an exceedingly ingenious contrivance, and would be highly valuable for all purposes where great regularity of motion was required. He had himself employed one of the former chronometric governors with the conical pendulum on one of the engines at his works in Manchester for many years, and it was found to answer exceedingly well; ultimately however it had fallen into disuse, not from any defect in the principle of the governor, but simply from the engineman not taking the requisite care to keep it in proper order, so that the friction could no longer be relied upon as definite. There was no doubt however that the governor might be considered successful in giving a uniform motion to steam engines, and also to astronomical instruments, as shown by the fact of its being employed by the Astronomer Royal for regulating the motion of one of the equatorial telescopes in the Greenwich Observatory. In the small governor now exhibited at work upon the electric clock he observed that the revolving cup was connected to the driving spindle by a light spiral spring, which allowed for the vertical movement of the cup in working; and he enquired what took the place of this spring in the other form of the governor as applied to steam engines.

Mr. Siemens explained that in both the forms of the chronometric governor described in the paper the fundamental principle of action was the same, namely that the resistance offered by the liquid raised in the cup was employed as the governing power for effecting the control of the speed; but the different mode of applying this power for the purpose led to the difference of construction in the two forms of the governor. In the delicate governor employed upon the electric clock, the revolving cup was driven directly by the driving spindle through the spiral spring, and the bush by which the cup was carried upon the spindle was a quick-threaded screw; so that when the proper speed was exceeded the cup dipped deeper in the liquid and took up a larger quantity, whereby the resistance

to the driving power was increased; while any slackening of speed below the proper amount caused the cup to rise partly out of the liquid, and the resistance was diminished to a corresponding extent. In the steam-engine governor on the other hand the revolving cup was not driven by the engine at all, but by the constant weight upon the lever of the throttle-valve spindle; this weight was constantly trying to fall, while the engine was constantly trying to lift it through the differential wheels. These wheels were geared together in the proportion of four to one, so that the governor cup made four revolutions for one of the engine. The cup however had no vertical motion in this case, but the effective resistance of the liquid overflowing from it was increased by the set of fixed vanes placed round the circumference of the external chamber and the corresponding set of blades fixed round the outside of the cup. The throttle-valve weight acted upon the centre pinion of the differential gearing, and the pinion was allowed to yield to the weight, but only at the fixed velocity determined by the resistance of the liquid to the revolving cup. Hence if the engine attempted to go faster than the proper speed allowed by the governor, it would wind up the weight faster than the governor allowed it to fall, and the throttle-valve would instantly be partially closed by the weight lever acting direct upon it; while if the engine failed to wind up the weight fast enough, the governor would let it fall, and the throttle-valve would be further opened; so that in either case the speed of the [redacted]

the irregularities of the work, a very important point would be accomplished; and from the particulars which had been given respecting the working of the new governor there appeared to be no doubt that this object was now effected, and he should be glad to have an opportunity of seeing the governor in actual work. He enquired whether there was not some little difficulty in practice from the evaporation of the water in the governor, and what means there was of keeping the supply always up to the proper level; and also whether mercury had been tried instead of water, and what difference in the working of the governor was found in that case as compared with the use of water.

Mr. Siemens replied that the level of the water in the governor was shown by a glass gauge tube fixed on the side of the chamber containing the revolving cup, and alongside the tube was a scale, upon which were marked the number of revolutions per minute of the engine corresponding to the different levels of the water; the addition of water caused the speed of the engine to be diminished, and a reduction of the quantity allowed of a higher speed. The chamber containing the water was closed at the top, so that no evaporation could take place; and the only place where any escape of vapour could possibly occur was through the centre bearing of the driving spindle, which was made sufficiently easy for the spindle to run freely; but as there was no circulation of air through this bearing, there would in practice be no escape of vapour through it. He had not tried the use of mercury in the governor, but the specific gravity of the liquid had no influence on the speed of the revolving cup, although the power of the instrument for overcoming the resistance of the throttle-valve was increased by an increased density of the liquid; so that the specific gravity of mercury being fourteen times that of water, a governor working with mercury would have fourteen times the power of one of the same size in which water was used.

Mr. Fairbairn enquired whether the power of the governor was not affected by the quantity of water contained in the chamber in which the revolving cup worked.

Mr. Siemens explained that the quantity of water did not affect the power of the governor but only its speed, since the amount of

the overflow regulated itself according to the speed at which the cup was driven; and therefore supposing, while the engine and governor were running at the proper speed, the quantity of water in the chamber was suddenly increased by the addition of more water, the only result would be that more water would be taken up by the revolving cup and a larger overflow would be produced, which would instantly increase the resistance to the rotation of the cup, and cause it to run at a lower speed, thereby reducing at the same time the speed of the engine to the lower rate corresponding with the larger quantity of water. The water was in reality a liquid break, which absorbed instantly all the surplus power that might be applied to drive the governor, and thus kept the speed of rotation of the governor practically the same at all times.

Mr. W. M. Neilson suggested that a small pneumatic water feed might be attached to the governor for preserving a constant level of water, if there were any possibility of water being lost by evaporation or leakage; as it would be very inconvenient to find the speed of the engine becoming increased by a gradual diminution in the quantity of water contained in the governor.

The Chairman enquired how long the governor had been found to continue in work at the proper speed without requiring any renewal of the water supply.

Mr. Siemens replied that the governor had never been touched for the purpose of adding water to it since it was first put to work

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interfere with the effect of the weight upon the throttle-valve lever, by which the revolving cup of the governor was in effect driven; and he suggested that the difficulty might be obviated by substituting a spring in place of the weight.

Mr. SIEMENS said it would certainly be necessary to employ a spring instead of the weight on the throttle-valve lever, in applying the governor to marine engines.

Mr. C. E. AMOS remarked that he had tried the previous form of the chronometric governor, with the conical pendulum and friction break, and could bear testimony to its complete efficiency and perfect accuracy in keeping the speed of the engine correctly to the proper rate, so long as the friction break continued in proper order. The practical difficulty however was the lubrication of the break; and as there was not the means of ensuring its being kept uniformly lubricated, the governor ultimately went out of use. But in the new governor now described, the correctness of its action did not depend upon friction, but upon the resistance produced by the liquid overflowing from the revolving cup; and he therefore thought the new governor was not only a very good one in principle, but would prove thoroughly successful in practice. With regard to the application of the governor to marine engines, he enquired whether the disturbance occasioned in the liquid by the vertical pitching of the vessel would not materially affect the proper working of the governor.

Mr. SIEMENS replied that the oscillations in the liquid in consequence of the pitching of the vessel would be by no means so extensive as might be imagined; this was shown already in the case of the ship's compass, which floated on water without exhibiting any excessive amount of motion, and the water was subject in that case to exactly the same variations in level that would occur in the governor. Moreover the bottom of the chamber containing the revolving cup might be made hemispherical, with the apex of the cup in the centre, in which case the oscillations of the liquid in the chamber would not affect the depth of immersion of the cup at all. The principle of gyration in fact counteracted the effect of gravitation, and the overflow from the rim of the cup would remain

uniform whether the axis of the cup were vertical or tilted. A sudden vertical pitching of the vessel could only have the effect of very slightly increasing the force of gravitation in pitching upwards, and very slightly diminishing it in pitching downwards, tending in the former case to diminish the overflow from the revolving cup, and in the latter case to increase it. But the mean result would be the same as if no pitching took place, inasmuch as the governor cup had a considerable momentum in revolving; and therefore even if any such irregularities occurred in the overflow they would perfectly compensate themselves, without affecting the speed of the governor.

Mr. E. A. Cowper observed that an important feature in the new governor was the facility that it offered for varying the speed at which the engine was to run, as it was only necessary to alter the level of the water in the governor by means of the gauge glass at the side, in order to change the speed to any different rate; the addition of water would reduce the speed to a lower rate, or the speed could be increased by running off some of the water out of the governor.

Mr. C. E. Amos remarked that the same object might also be accomplished by shifting the weight upon the throttle-valve lever, if that were preferred, without altering the water level in the governor.

The Chairman thought the new governor was a most important

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ON AN IMPROVED CONSTRUCTION OF WROUGHT IRON TURNTABLE.

By Mr. WILLIAM BAINES, of Soho.

In the improved construction of Wrought Iron Turntable, forming the subject of the present paper, the object of the writer has been to obtain a turntable made entirely of wrought iron, but with uniform depth and strength throughout the top; and with all the portions combined together solid, like an ordinary cast iron top, thereby preserving the stiffness and solidity of a cast iron table together with the toughness and strength of wrought iron. This construction further gives the advantage of great saving in weight, and facility of conveyance; as the top of the table takes entirely to pieces, instead of being composed of bulky castings.

The construction of the turntable is shown in Figs. 1 to 4, Plates 5, 6, and 7. Fig. 1, Plate 5, is a vertical section of a 12 foot table; and Fig. 3, Plate 6, is a plan of the same table. Fig. 4, Plate 7, is a plan of an 18 foot table.

The top of the turntable is constructed entirely of wrought iron girders, formed of bars rolled to a special section, as shown in Fig. 8, Plate 10, drawn half full size, so as to fit into one another when placed together side by side; and these are framed together in such a manner as to form a continuous rigid girder in all directions, as shown in the plans, Figs. 3 and 4. The section of one of the combined girders is shown at AA in Fig. 1, and also drawn half full size in Fig. 9, Plate 10. Only one form of section of iron is employed, as shown in Fig. 8, the bar being rolled with two ribs and a groove or channel between them, running along one edge of the plate and upon both sides, and a single rib and groove of the same pitch running along the other edge of the plate on both sides; so that by reversing the bars alternately top and bottom edge upwards, as shown in Fig. 9, the ribs and grooves fit into one

another with complete accuracy, and the several bars are thus checked into one another along their entire length, as seen in the specimens exhibited. The bars are $7\frac{1}{4}$ inches depth and $\frac{3}{8}$ inch thickness, weighing 12 lbs. per foot.

In this arrangement the bolts which secure the bars together are all of them merely fishing bolts, having simply to hold the bars together laterally, without being exposed to any transverse strain; as the bars are held from sliding upon one another vertically by the ribs and grooves along their edges, thereby relieving the bolts from all transverse strain. The bars can thus be cut into pieces of any length required, and then joined together in any lengths and at any places by bolting them together; and they then form a single continuous solid girder of uniform depth throughout.

The use of this ribbed and grooved section of bar for constructing the girders of the table allows of increasing the strength of the girders towards the centre of the table without increasing their depth, by the insertion of an additional bar in the length nearest to the centre, thus increasing the thickness of the girders towards the centre, as seen in the plans, Figs. 3 and 4. Thus in the plan of the 12 foot table, shown in Fig. 3, the four main girders BB radiating from the centre pin are each composed of three bars bolted together; but beyond the points where they cross the lines of rails on the table, the middle bar alone is continued straight onwards to the rim of the table, while the two side bars are turned

The position of the girders forming the top of the turntable is arranged to coincide with that of the rails, which are carried upon the top of the girders, and are bolted down upon them by countersunk bolts passing down through the space between the bars of the girders, as shown by the dotted lines at DD in Fig. 1. The rails are thus independent of the structure of the turntable, and can therefore be readily renewed in the same manner as ordinary rails when worn out, without requiring any portion of the turntable to be taken to pieces for the purpose, as they form no part of the framing of the table.

The outer rim EE, Fig. 1, of the turntable top forms the upper roller path, and is constructed of bar iron rolled to the section shown half full size in Fig. 10, Plate 10, ribbed and grooved along the inner edges to correspond with the bars forming the girders. This bar is bent to the required circle of the rim, and the ends are fished together with a butt joint, with outside and inside cover plates. There is no turning required for the face of the roller path, as the rolled bar iron is sufficiently true for the purpose, having as true a surface as the ordinary railway rails. The lower roller path is an ordinary T rail bent to the proper circle and laid upon timber sleepers. The rollers FF are of cast iron, and the live roller frame consists of a ring of plain bar iron, with an external bracket bolted on at each of the rollers, the roller spindles being connected to a ring turning loose round the centre pin.

The centre pin G, Fig. 1, and the foundation plate or socket carrying it, are of cast iron. The top end of the pin is bored out, as shown enlarged in Fig. 2, and a piece of wrought iron I, faced with steel, is let in, to form the centre bearing for the top of the turntable. The surface of the steel is spherical, bearing against a corresponding spherical chilled surface on the under side of the cast iron cap H, to which is bolted the centre cross J of the turntable top. The space left in the recess at the top of the centre pin forms an oil cup, for lubricating the bearing surfaces. The only cast iron employed in the table is therefore for the rollers and for the centre pin and connections. The centre cross J, which was

previously made of cast iron, is now made of wrought iron in a single forging, as shown in Figs. 6 and 7, Plate 9, with the advantage of greater strength and lightness. The wrought iron centre piece consists of a strong welded tube, bored out to fit the centre pin G of the turntable, and grooved outside on the four sides to receive the ribs of the bars composing the girders, which are bolted to it with countersunk bolts, as shown in the drawing. The four suspending bolts for the turntable top lay hold of a wrought iron washer plate K underneath.

The bars composing the girders of the turntable top are bent hot by hydraulic pressure, as shown in the plan, Fig. 12, Plate 11. Where two or more of the bars have to be bent to fit one another, they are made to fit by simply bending one upon the other in their permanent position, the bar first bent forming then the block for bending the second upon, and so on, which ensures each one being thoroughly bedded upon the others. The same die L is made available for bending all the bars, by having one jaw of the die formed of a sliding block M, which is adjusted by a hand screw to suit each successive increase of width of the bend in the outer plates, the die L itself being loose from the ram of the hydraulic press, so as to slide laterally to the extent requisite with each successive increase of width in the jaw. The correct position of the bend is ensured by the simple means of the fixed stud N, which enters the permanent bolt hole previously punched in each

There is a great saving of weight in the present wrought iron turntable, the weight of which is less than one half that of cast iron tables of the same size :—

the	12	foot turntables	weigh	only	3½	tons	instead of	7½	tons
„	15	„	„	„	4½	„	„	10½	„
„	18	„	„	„	5½	„	„	13	„

This saving of weight is an important advantage in reducing the labour of fixing and removal; and the tables can be readily moved and loaded or unloaded, without the tackle requisite for the heavy castings of the ordinary tables. In sending the tables to distant countries not only is the total freight and cost of conveyance reduced two thirds, but in consequence of the construction of the tables admitting of readily dividing them into portions all of small weight, great facilities are afforded for conveying them into difficult situations.

The reduction in weight also renders the tables easier to turn, and thereby diminishes their wear and tear; the weight of the turntable top in comparison with a cast iron top being

in the	12	foot table	1¾	tons	instead of	2¾	tons
„	15	„	2½	„	„	4¼	„
„	18	„	3½	„	„	7¾	„

The depth of these turntables is considerably less than in most other tables, being only 20 inches total depth both in the 12 foot and 18 foot tables, in consequence of the compactness of the construction. The depth of the pit and excavation for the foundations are therefore proportionately diminished, which is an important advantage in situations where drainage is difficult.

This turntable has a special advantage in facility of construction and adaptation to different circumstances, as compared with the cast iron tables and those constructed of wrought iron and cast iron combined. In those cases patterns are required for the castings, and a different pattern is necessary for each different size of turntable, however small may be the difference in diameter; a different pattern is also necessary in each size of table for every different gauge of rails and for every variety in position of the rails,

whether a single line of rails, or double lines at right angles, or with oblique lines at 45° or 60° inclination. The cost and time of construction is thereby materially increased in the cast iron tables, causing delay in producing any tables adapted to meet special circumstances, and seriously increasing the expense where a few only are required of the same kind.

In the wrought iron turntable now described these difficulties are entirely removed. As the table consists of merely a repetition of the same pieces, varying only in length and angle of bend, any desired alteration in diameter is readily effected, however fractional in amount, by simply altering the lengths of the bars accordingly, without affecting the construction of the joints. The table can also be made to suit any direction or number of the lines of rails, by making the angle of the bends and the lengths of the bars to correspond; and the same facility applies also to the adoption of any gauge of rails. In Fig. 5, Plate 8, is shown a plan of a four-line turntable having four lines of rails inclined to one another at 45°, showing the mode of arranging the bars in the turntable for carrying each of the lines of rails.

In Fig. 3, Plate 6, is shown the most general arrangement of turntable with two lines of rails at right angles for a main line turntable; and in Fig. 4, Plate 7, is the arrangement with a single line of rails for engine turntables. A similar construction is applicable when a double gauge of rails is required on each of the

requiring it to be taken up for the purpose, and without delaying the traffic longer than is requisite for drilling the bolt holes and bolting the bars in, which can be done at intervals according to convenience.

These tables are now being manufactured for five different gauges of railway, and of all the different sizes in general use, without employing any patterns whatever for the different sizes and forms; all that is required being the templates for diameter of circles and lengths of the several pieces of which the table is composed.

These tables have been at work more than three years, and exposed to the severest tests of working; but no failure or fracture has occurred in them or any sign of injury, although in the same time with cast iron tables there would unavoidably be considerable failure from breakage. One of the 12 foot tables on this construction has been tested with a load of 40 tons, and one of the 18 foot tables with a load of 50 tons, without the slightest injury resulting to the tables.

Mr. BAINES exhibited sections of the bars composing the girders of the turntables, and also a segment of one of the turntables, showing the mode of framing the bars together.

The CHAIRMAN enquired how many of the turntables on this construction were now at work.

Mr. BAINES replied that there were now about 100 of the turntables at work, and they had proved so satisfactory that in every case where the new tables had been tried, their use had been extended.

The CHAIRMAN enquired whether the same construction would answer for the turntables now necessary to be used in turret ships, which were required to be about 25 feet diameter and to carry a weight of about 200 tons. He thought if the wrought iron turntables

could be adapted for that purpose they would be very advantageous, on account of their lightness in comparison with the present heavy cast iron tables. The present tables were usually made to turn upon stationary rollers fixed on the deck, instead of live rollers running round in a frame, as shown in the drawings.

Mr. Baines replied that one of the wrought iron turntables of 12 feet diameter, composed of bars $7\frac{1}{4}$ inches deep, would readily carry a load of 100 tons without injury; and there would therefore be no difficulty in making tables of 25 feet diameter to carry 200 tons, by using bars of greater depth and thickness for the purpose. Such tables would have the great advantage of being very simple to repair, as they could be easily repaired in a very short time if disabled in war.

The Chairman enquired whether there had been any difficulty in rolling the bars of the particular section shown in the drawings; and whether the rolling was done with sufficient accuracy to ensure the bars going together correctly in constructing the turntables.

Mr. Baines replied that the rolling was found to be done with complete accuracy, and it would be seen from the sections now exhibited of the girders that the bars went together with perfect correctness, fitting tight into one another when put together just as they came from the rolls, as the ribs and grooves in the successive bars corresponded exactly to one another and their surfaces were quite smooth and clean.

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was then securely fished on each side by an external cover plate. The strength in this construction could also be increased to any extent by simply increasing the width of the girders by the addition of any number of bars, and the greatest strength was obtained at the parts where it was required, in the top and bottom of the girders; moreover the expense of labour in making girders on this principle was the least possible. Another advantage was that the outside bar of the girders might be rolled externally of any special section that might be desired for ornamental purposes; just as in the turntables shown in the drawings, the bar forming the circumference of the tables was rolled to the particular section shown, in order to form the upper roller path: and two of these bars bolted together back to back with an intermediate bar between, as shown in Fig. 11 and in the specimen exhibited, formed a double-edged angle-iron section, which could also be used for the purpose of running over rollers. This ribbed section of iron was on the whole the simplest and best section he had yet seen for general purposes of iron construction, such as shipbuilding, warehouse girders, and railway purposes; and for the sole plates of railway rolling stock it might also be advantageously employed.

Mr. W. M. Neilson considered the section of iron was certainly a very good one mechanically, and very cleverly designed for making the ribs and grooves fit together with such nicety by simply inverting the same section of bar.

The Chairman enquired whether it was thought that girders put together in the manner that had been described with butt joints would be as strong at the joints as in the solid.

Mr. R. Williams replied that the butt joints were made really the strongest parts of the girders by the addition of the external cover plates on each side of the joint; and it must be borne in mind that these cover plates, being made of the same section of iron, were not like ordinary plain cover plates, where the strength of the joint depended upon the security of the bolts or rivets by which the cover plates were secured; but the ribs and grooves caused the cover plates throughout their entire length to be checked into the main bars of the girder, and thus made the strength even greater

at the butt joints, while the bolts simply held the plates together, without being themselves subjected to any transverse strain. No welding was therefore required in putting the girders together, whatever length might be required, and the risk of failure through defective welding was thus obviated.

Mr. E. Jones said the wrought iron turntable described in the paper was the best and strongest turntable for its weight that he had ever met with; and they were now making a large number of these tables at the Old Park Iron Works, Wednesbury, to go out to India.

Mr. J. Pettifor enquired what was the cost of the new turntables, exclusive of the foundation, in comparison with that of the ordinary cast iron tables of the same size.

Mr. Baines replied that the cost of the wrought iron turntables was about the same, but the strength was three times as great as that of the ordinary cast iron tables of the same size.

Mr. E. A. Cowper thought the construction of the wrought iron turntable was highly ingenious, having the bars of the girders joggled into one another continuously throughout their whole length, so that the bolts were merely fishing bolts with but little strain upon them. This mode of construction gave the means of increasing the strength of the girders at the parts where required; and it was seen from the drawings that towards the middle of the table the girders were composed of three bars bolted together, while at the outer ends

the load by two men, because the facility of turning depended of course upon the stiffness of the girders, by which the load was prevented from coming too heavily upon the rollers of the table. With regard to the curving of the bars at the centre of the table, the object of this had been to make the girders continuous in all directions throughout the table, which was rendered possible in this construction of table in consequence of each girder being composed of several separate bars bolted together. By this means also the girders were united to the casting forming the centre boss. In one of the earliest tables put to work the centre casting had been a very light one and had been broken; but it was so securely held in its place that it had still been kept at work, and had continued so for three years under a heavy traffic without any difference, and it had not been thought worth while to replace it by a new casting. As it was desirable however to avoid any risk of accident by breakage of the centre casting, he had now adopted a wrought iron centre instead, as shown in the drawings, so that the entire moveable top of the turntable was now made of wrought iron.

Mr. E. A. Cowper enquired whether it was intended to weld the bars of the girders to the wrought iron centre, so as to make a solid forging in the centre; this would probably make a very sound job.

Mr. Baines explained that there was no welding, but the wrought iron centre boss was simply grooved on the four sides to receive the ribs of the bars, which were then securely bolted to it in a similar manner to the other joints of the table.

The Chairman moved a vote of thanks to Mr. Baines for his paper, which was passed.

The Meeting then terminated; and in the evening a number of the Members dined together in celebration of the Nineteenth Anniversary of the Institution.

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PROCEEDINGS.

3 May, 1866.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 3rd May, 1866; Henry Maudslay, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

William Baines,	Soho.
Clement Barnard,	Birmingham.
Restel R. Bevis,	Birkenhead.
Andrew Betts Brown,	London.
Charles Cleworth,	Jumalpore, India.
William Daniel,	Shrewsbury.
Walter Fiddes,	Bristol.
Charles Douglas Fox,	London.
George Haden Hickman,	Tipton.
Charles Hodgson,	Portarlington.
Thomas Holcroft,	Bilston.
John C. A. Houghton,	Dudley.
Joseph Foster Lloyd,	Wednesbury.
Richard Norfolk,	Beverley.
John Hartley Perks,	Wolverhampton.
Aleksander Scholtze,	Warsaw.
Frederick Turner,	Ipswich.

The following paper was then read:—

ON THE CORROSION OF LOCOMOTIVE BOILERS, AND THE MEANS OF PREVENTION.

By Mr. WILLIAM KIRTLEY, of Derby.

From the reports of accidents with Steam Boilers in this country during the last year 1865, it appears that during that period 55 steam boilers have exploded, causing the deaths of about 56 persons and injury to a much greater number. Amongst these explosions there have been on the railways of the United Kingdom out of 7000 locomotives 11 boilers exploded, causing loss of life and injury in each case, and in addition serious destruction of property. Each of these explosions must have been occasioned either by defects of construction or material, or else by negligent supervision. It is intended in the present paper to consider only the subject of high-pressure boilers, such as those of locomotives; and as in the large majority of exploded locomotive boilers it has been found that the explosion has arisen from the plates of the boiler having become weakened by corrosion at particular places, it is the writer's object to describe the nature and extent of this corrosion, and to endeavour to show the causes of its occurrence, together with the means of [redacted]

work. A similar grooving also takes place along the edge of the inside lap at the longitudinal joints, as at D and E in Fig. 6, and also at the transverse circular joints, as at BB in Figs. 4 and 5; but in the latter case the grooving does not occur so frequently nor is the extent of corrosion so great as at the smokebox end and at the longitudinal joints, as seen in the specimens exhibited of corroded plates from the different situations.

It has to be remarked first that this grooving is only found below the water line, showing that it must be due to the chemical action of the water on the plates; and the special point to be enquired into is the cause of this action being so remarkably concentrated at the particular lines where the grooving takes place. It will be seen from the specimens shown, which are taken from locomotive boilers that have been at work for various periods of from three years to as much as nineteen years, that some corrosion also takes place over the general surface of the plates; but this is very limited in extent compared to the grooving at the seams, and it occurs very irregularly, being apparently influenced by some irregularities in the structure of the plates, causing them to be pitted irregularly by the corrosion.

In the ordinary construction of locomotive boilers with lap joints, as shown in Figs. 7 and 8, Plates 13 and 14, the barrel of the boiler is constructed of three rings, each ring formed by two plates of 7-16ths inch thickness, rivetted with lap joints FF and HH. The general amount of lap is $2\frac{1}{4}$ inches for single-rivetted and $3\frac{1}{2}$ inches for double-rivetted joints. The smokebox and firebox are each united to the barrel of the boiler by an angle iron KK, Fig. 8, 3 inches or $3\frac{1}{2}$ inches wide, welded into a ring. General experience has shown that after five or six years' wear of these boilers the grooving action that has been described is developed at the joints and at the edge of the angle-iron rings.

Now the longitudinal strain upon the joints of boilers constructed in this manner tends to spring and bend the plates at the joints, when under pressure, into the form shown exaggerated in Fig. 9, in consequence of the plates not being originally in the line of strain,

as shown by the dotted line SS in Fig. 8, which it will be seen runs along the outer face of one plate and the inner face of the next. Also in the longitudinal joints of the barrel, shown at FF in Fig. 7, a similar mechanical action takes place, the strain acting in the true circle shown by the dotted line SS, springing and bending the plates at the edge of the joints, as shown at GG, each time that the boiler is under pressure. The continued alternation of expansion and contraction in the boiler causes the scale that is deposited upon the plates from the water to be continually broken off at the edge of the joints by the mechanical action of this springing and bending of the plates at the lines of the joints; and the plates are thereby laid bare at those parts and kept continually exposed to the corroding action of the water, instead of being protected from the action of the water by the deposited scale remaining attached to them.

Though the corrosion produced by the water is slow in action and but slight in effect on the rest of the boiler plates, which are protected by some deposit of incrustation remaining almost constantly upon them, it becomes very serious on an exposed raw surface of iron; and this action is particularly severe in the case of locomotive boilers, in consequence of the total quantity of water evaporated in a locomotive boiler being much greater in proportion to the surface of the plates than in stationary boilers. The particulars are given in [redacted]

Particulars of Locomotives from which Specimens of Corroded Plates were taken.

Number of Engine.	Years of Working.	Miles run.	Water consumed. Gallons.
99	3	83,349	1,462,774
121	11¾	334,711	5,874,178
123	12	290,380	5,096,169
141	8¼	268,679	4,715,316
162	8¾	255,042	4,475,987
187	8½	229,099	8,041,374
235*	14	315,227	11,064,467
250	14¾	316,391	11,105,324
255	14	293,559	10,293,920
274	13½	303,249	10,644,039
306	11¼	229,162	8,043,587
306†	6¼	142,808	5,012,560
369	10½	246,956	8,668,155
375	3¼	67,072	2,354,227
388	8¼	180,985	6,352,573
410	6¾	158,801	5,573,915
422	8½	231,035	8,109,328
658	18¾	249,672	4,381,743

* Flanged tube plate. † After renewal with thick-edge plates.

It must further be noticed that the pressure under which the locomotive boilers are worked is much higher than in the case of stationary boilers, and the injurious action caused by the springing of the plates at the joints is therefore proportionately increased; and taking the pressures at 35 lbs. per inch for the stationary boiler and 140 lbs. for the locomotive, this makes the action four times greater in the locomotive boiler from this cause, taking the increase to be only at the same rate as the increase in pressure. Hence as the action is six times greater from the previous cause, a total is given of twenty-four times as great an extent of injurious action in the locomotive boiler as in the stationary boiler in the same length of time. As an illustration of the effects of increased pressure in increasing the corroding action, it may be mentioned that this grooving of the plates has been found to be materially increased in

amount since the working pressure of locomotives has been increased from 100 lbs. up to the present 140 lbs. per inch.

In some of the older classes of locomotive engines the writer has found that there is an increased local action of serious amount caused in the boilers by the rigid points of attachment to the boiler barrel, such as frame stays, brackets, &c., which offer special points of resistance to the expansion of the boiler when under pressure. A specimen of this grooving, taken from No. 187 engine in the preceding Table, is shown at CC in Figs. 4 and 5, Plate 12, caused by the rigid attachment of the spectacle-bracket M to the boiler barrel. The result is made worse when the firebox is rigidly fixed to the frames, or not allowed full freedom for expansion by the provision of a sliding bracket; as a great additional strain is thereby thrown on the tube plate, springing the angle irons round the ends of the boiler. The expansion of a 10 ft. 6 ins. or 11 ft. boiler barrel being about 3-16ths inch at a pressure of 140 lbs. per inch, an attachment to the frame at any other place besides the fixing of the cylinders and tube plate at the front end must subject the boiler to a bending strain at the points of attachment, causing a risk of corrosion at these points. In the Midland Railway engines all the other attachments except the smokebox angle iron are now removed, including that of the motion plate which carries the inner ends of [redacted]

plate by the same action. It must be borne in mind that the earthy deposit itself, being chemically neutral, cannot have any injurious action upon the plate; except in the case of a stationary boiler heated from an external flue, where undue heating and expansion of the plate are caused wherever its inner surface is separated from the water by any considerable thickness of non-conducting deposit.

In the preceding Table are given the particulars of seventeen locomotives on the Midland Railway, from which the specimens now exhibited of corroded plates were taken; showing the length of time of working and the mileage and consumption of water before the plates had become so defective as to require removal. The average result is $10\frac{1}{4}$ years' working, 255,645 miles run, and 7,618,778 gallons of water consumed by each engine.

In the case of the boilers constructed in the ordinary manner, as already described, the plates cut out show the grooving action of the corrosion below the water line, while they are comparatively clean above. In No. 235 engine the tube plate was flanged and rivetted inside the boiler barrel; and the result of working shows the advantage of this mode of construction over the ordinary angle-iron joint, since the plates at the smokebox end are not grooved along the end of the flange, as they would have been with an external angle iron.

From the foregoing consideration of the subject it therefore appears that the special corrosion of the plates at the joints is to be attributed to the combined operation of chemical and mechanical causes, the chemical action of the water in the boiler being concentrated upon those particular parts in consequence of the mechanical action produced at those parts by the strain upon the plates. That the combination of these two causes is requisite for producing this effect is shown by the middle of the plates being free from it, where they are exposed to the chemical action alone, without the mechanical action; and further by the joints in the upper part of the boiler above the water line being also free from it, where exposed to the mechanical action alone, without the chemical action. The removal of one of these causes will therefore be

sufficient; and in the locomotive boilers now to be described this object has been aimed at by removing the mechanical cause which produced the springing of the plates at the joints.

From the particulars already given of the corrosion which takes place in locomotive boilers, it appears that the greatest injury takes place at the smokebox end of the barrel, where there is not only a great and sudden change in the thickness and rigidity of the plates at the edge of the angle iron, as at J in Fig. 8, but also a leverage for the springing of the plate from the outer line of rivets, as at L in Fig. 9. The consequence is the bending of the plate at the point J, as in Fig. 9, each time of being under pressure of steam, owing to the outer line of rivets L being entirely outside of the line of strain S of the boiler plates. There is also a great tendency to injury of the angle iron, by this action tending to split it between the rivet holes at the outer line of rivets L.

The present plan adopted on the Midland Railway is found to obviate the injury previously experienced from corrosion; and this is accomplished by the use of plates rolled with thickened edges, as shown in section in Fig. 19, Plate 17, and shown exaggerated in thickness in Figs. 10 and 11. The ordinary thickness of 7-16ths inch is preserved in the body of the plate, and the edges are thickened to 5-8ths inch, with a long gradual taper in the thickness from I to

[redacted]

The practical working of the thick-edge plates is shown by the specimen exhibited from No. 306 engine in the preceding Table. The original boiler of this engine, constructed in the ordinary manner, was removed after $11\frac{1}{4}$ years' working, as the plates were much grooved and pitted; and a new boiler constructed with the thick-edge plates was substituted, which has continued at work $6\frac{1}{4}$ years to the beginning of the present year. It was then found that the plates were free from grooving, although they were badly pitted.

A consideration of the ordinary construction of locomotive boilers and their defects shows that their construction admits of important improvement in the barrel, by removing the injurious strains resulting from the employment of lap joints, which throw the plates out of the line of strain, and by making the barrel truly cylindrical and circular throughout. These objects are effected by welding the longitudinal joints of the three rings forming the boiler barrel, and making these rings all exactly the same diameter, uniting them to one another with flush butt joints. This plan is now carried out upon the Midland Railway, as shown in Figs. 16, 17, and 18, and exaggerated in thickness in Fig. 12, Plate 15. The meeting ends of each ring are turned in a lathe, and united by covering strips O O, formed of welded flush rings, shrunk on over the joints and double-rivetted. Strengthening hoops P P are also shrunk on the centre of each of the plates, crossing the longitudinal welded joints, and are secured by a few rivets. These hoops and covering strips for the joints are carefully blocked before being shrunk on, and the whole of the rivet holes are drilled after the hoops are in their places.

These boilers are consequently truly cylindrical at all parts, and no strain to which they are subjected has any tendency to change their circular form. The effect of the longitudinal strain upon the transverse circular joints, as in Fig. 13, is found to be altogether inappreciable in practice, because the covering rings O O could not yield to it without contracting in circumference in the form of a double cone, Fig. 13; and on this account, together with their greater thickness, they offer a greatly increased resistance as compared with simple lap joints. All possible effect of the

longitudinal strain might indeed be entirely got rid of, if desired, by the further addition of inside covering strips at the butt joints, as shown in Figs. 14 and 15. At present the circular plates of these welded boilers are in two semicircular segments for the circumference of the boiler, and therefore require two welds; but the writer thinks the barrel of the boiler would be improved if each length were made of one plate only, whereby only one longitudinal weld would be necessary.

A remarkable corroboration of the correctness of this mode of construction is given by the samples exhibited from No. 658 engine, the boiler of which was constructed with butt joints all flush throughout, the transverse joints being covered by external hoops and the longitudinal joints by internal strips. This boiler has been at work nearly 19 years, having been started in 1847; but the engine being of smaller size than those now used with trains has only been employed as a spare engine for some years past. The plates of the boiler, which are the original ones and have never been repaired at any part, are all good, and the grooving has not taken place at the butt joints, a little irregular pitting alone being visible on the inside of the plates. The boiler has now been cut up only on account of the engine being abandoned from the great length of time it has been worked. The remarkable contrast shown by the freedom of the butt joints in this boiler from the grooving so

[redacted]

The Flanging Machine is shown in Figs. 20 to 22, Plates 18 and 19. It consists of a horizontal table A, on which the thick-edge plate, shown black, having been previously heated, is laid and secured by clamps, being pushed forwards against the adjustable stop B, Figs. 20 and 21, so that the thick edge projects beyond the edge of the table to the required extent for forming the flange. The roller C is then brought down with a slow motion by the eccentrics D, as shown in Fig. 21, being firmly held by guides E at each end in the frame of the machine; and the edge of the plate is thus gradually bent down to form the flange. The table A is made to slide upon the bed F of the machine, and is set up by adjusting screws G to the required amount of clearance from the bending roller C, according to the thickness of the plate to be flanged. The front edge of the table is faced with a separate wrought iron or cast iron edge-piece I, which can be removed and changed for another having a different curve for the edge, according to the curve that is desired in the neck of the flange. The holding-down bar H is screwed down tight upon the plate, immediately behind the edge of the table, so as to hold the plate down flat on the table while the flange is being bent by the roller. The working speed of this machine is 7 double strokes per minute.

The Bending Machine, for bending the thick-edge plates into the semicircle to form the boiler barrel, is shown in Figs. 23 and 24, Plates 20 and 21. It consists of three horizontal rollers, of which the two lower ones AA are carried in fixed bearings at each end in the frame of the machine; while the third roller B slides vertically in the frame, and is lowered by the screws CC at each time of passing the plate through the rolls, to give the required degree of curvature to the plate. The screws CC were at first worked by hand, but are now driven by gearing from the main shaft. As the thickness of the body of the plate is only 7-16ths inch, while the thickness of the edges is 5-8ths inch, a liner plate 3-16ths inch thick is laid over the body of the boiler plate in the bending process, in order to make up the same thickness of 5-8ths inch throughout for passing through the rolls; and the liner plate is afterwards flattened again ready for subsequent use. At one end of each of the lower rollers AA is a

groove D to receive the flange of the plate; this groove is shown enlarged in Fig. 26, and is formed by a glut-piece or ring E, screwed upon the roller spindle F and tightened by a set screw G, by means of which the width of the groove can be increased or diminished according to the thickness of the flange of the plate. A corresponding groove is provided at the opposite end of the upper roller B, to allow of bending plates with the flange inside instead of outside. In order to obtain a sufficient hold upon the plate to pass it through the rolls, the surfaces of all the rollers are fluted longitudinally with shallow flutes at $1\frac{1}{4}$ inch pitch, as shown in Fig. 26, and enlarged to half full size in the section, Fig. 25. The lower rollers only are driven by gearing, the upper roller being merely a pressing roller for giving the required curvature to the plates, and weighing about 25 cwts. The working speed of the rollers is 3 revolutions per minute, or about 12 feet per minute speed of surface.

The two semicircular plates are then welded together into a single ring to form one length of the boiler barrel. The edges to be welded are first heated in the fire at A, Fig. 29, and upset sufficiently to give the required thickness of metal for forming the scarf weld. A welding heat is then taken on a short length of the joint of the plates, and the plates B are welded together along the joint upon the Welding Anvil, shown in Figs. 28 and 29, Plate 22. The anvil face C is shaped to the internal diameter of the boiler [redacted]

circumference. The ring B to be heated is put in from the top, and placed on end, with the heat from the fire passing up through the inside of the ring and then down all round the outside to the flues, so as to give a uniform heat to the ring.

The ring is then put on the Blocking Press, shown in Figs. 32 and 33, Plate 24; which is an ordinary hydraulic wheel-tyre blocking press, worked by a centre cone D forcing out the blocking segments EE. These blocking segments are carried up for the purpose and strengthened by brackets, as shown in the drawing. One half of the height of the ring B is blocked at once; and the ring is then turned over for blocking the other half.

The welded joints of these boilers have been tested by a series of experiments upon the tensile strength of strips of plate cut out across the weld, which were taken from several boilers from the opening cut out for the steam dome R, Fig. 16. Three sets of strips were tested, of 1, 1⅜, and 1½ inch width respectively, and each 7½ inches length, cut out of the plate transversely to the weld, which was in the middle of each piece. The following was found to be the average breaking strength per square inch of these strips:—

Experiments to test strength of Welded Joints.

Width of Strips.	No. of Strips tested.	Broke in Weld.	Broke in Solid.	Breaking Strength per square inch.		
				Least.	Greatest.	Average.
Inch.				Tons.	Tons.	Tons.
1	15	8	7	16·5	23·8	20·2
1⅜	4	2	2	19·6	22·2	21·0
1½	4	1	3	18·1	23·5	21·7
Total	23	11	12	16·5	23·8	**20·6**
Also	11 Strips of the same plates *unwelded*			20·7	25·8	**23·6**

From these results it appears that more than half of the strips broke in the solid and not at the weld, and the average breaking strength

of the 23 welded plates was within 1-8th of the full strength of the 11 unwelded plates; while the worst pieces, including some cases of as extremely defective weld as are at all likely to occur in practice, had more than two thirds of the full strength of the unwelded plates.

In reference to the cost of construction of the welded boilers in comparison with the ordinary class of lap-jointed single-rivetted boilers with angle-iron ends, it has to be noted that there is an increase of weight of $1\frac{1}{4}$ ton in the new boilers, the weight of the 11 ft. boilers, 3 ft. 11 ins. diameter, being $7\frac{3}{4}$ tons as compared with $6\frac{1}{2}$ tons in the old class of boilers of the same dimensions. This increase arises from the thick-edge plates, and from the hoops and joint strips, which weigh about $2\frac{1}{4}$ cwts. each; and the joints, instead of being single-rivetted, are double-rivetted on each side of the joint, making four rows of rivets.

The total cost for labour and material is £465 in the new boiler, as compared with £415 in the old class, being an increase of £50 in each new boiler. The labour alone in the new boiler is £65 as compared with £55 in the old class, being £10 increase in the new boiler. In these costs however the whole labour is taken as hand work in both cases; but from the present experience it appears that the item of labour in flanging and bending is now reduced [redacted]

As yet however they show no signs of grooving even at the flanged ends, where the greatest corrosion took place in the old construction with the angle-iron joints. Two of these boilers have been examined twice, and were also found to be in good condition at the second examination.

Mr. W. Kirtley exhibited a large number of specimens of corroded plates from locomotive boilers of the ordinary construction, together with specimens of the thick-edge plates, flanged and bent; and also the strips of welded plate that had been broken in testing the strength of the welded joints.

Mr. W. Naylor thought the importance of the subject brought forwards in the paper just read was sufficiently established by the fact which had been mentioned of there having been as many as eleven explosions of locomotive boilers during the last year, due mainly to the effects of corrosion. The increase of pressure that had taken place in locomotive boilers during the last thirty-five years, from 50 lbs. to as much as 160 lbs. per square inch, had no doubt much to do with the repeated explosions that still occurred; and though he believed the high pressure of 160 lbs. had been adopted for the sake of economy in the application of the steam, he doubted whether economy was really gained by it in practice, taking into consideration the greater wear and tear of the boiler and gearing; but even if that were the case he thought that safety should be the first consideration, and economy might then follow. At present it was clear from so large a number of explosions having occurred during the past year that safety was giving way to economy; and he strongly recommended that the working pressure should be reduced from 160 lbs. to not more than 120 lbs. per square inch.

The construction of boiler described in the paper appeared to him certainly a step in the right direction, by getting rid of the strains which caused the corrosion to produce such serious effects in ordinary locomotive boilers. The defects of the present construction of locomotive boilers with rivetted lap joints, and the danger of employing a high pressure of steam with such a construction, were rendered apparent even in the testing of the boilers by hydraulic pressure, before they were put to work. For in testing boilers of 50 inches diameter in the barrel and 60 inches across the firebox, with water pressure up to 200 lbs. per square inch, the joints were found to appear sound up to about 150 or 160 lbs., but when the pressure was increased to 200 lbs. there were numerous leakages at the joints, showing that joints so made were not sound under so high a pressure. Taking the direct tensile strain upon the iron, if the plates were $\frac{1}{2}$ inch thick the tensile strain with a diameter of 60 inches and the pressure of 200 lbs. per square inch amounted to 12,000 lbs. or nearly $5\frac{1}{2}$ tons per square inch on the section of the iron; and therefore at the longitudinal lap joints there was a force of $5\frac{1}{2}$ tons per square inch acting at a leverage of $\frac{1}{2}$ inch to spring the joint open and bend the plates, while at lower pressures the strain upon the joints was proportionately less. Hence taking into account the continual variations of pressure to which locomotive boilers were subjected [redacted]

joints. The longitudinal tensile strain upon the plates forming the barrel of the boiler was not nearly so great as the lateral strain, for the area of the ends was much smaller in proportion to the circumference by which the strain was borne; but with the leverage afforded by the lap joints, this amount of strain was still sufficient to produce the serious grooving that was found at the transverse circular joints of the boiler barrel, and at the angle-iron joints at the smokebox and firebox ends.

The rivetting of the joints in boilers was also a source of weakness in the construction. For with the ordinary $\frac{7}{8}$ inch rivets placed at 2 inches apart centre to centre there was only 56 per cent. of the metal left at the rivetted joints as compared with the body of the plates. At the same time the plates were to a certain extent deteriorated by the strain put upon the iron in punching the rivet holes; and he had found by experiment that the strength was as much as 10 per cent. less after punching the holes, as compared with drilling them, when there would be no strain put upon the fibre of the iron in making the rivet holes. Altogether therefore the strength at the rivetted joints could not be taken as more than about 50 per cent. of that of the solid plates, and hence it was highly important that some other mode of uniting the plates should be adopted; and he thought the welding of the longitudinal joints, as described in the paper, was decidedly a good plan, and the specimens exhibited of the welded plates that had been tested showed that the welding had been very satisfactorily accomplished. Although this was the best mode of construction that had yet been adopted, it still involved the risk of the weld being unsound, to which all welding was exposed; and he believed there would be a still further improvement effected before long, by having the several lengths of the boiler barrel rolled each complete in a solid hoop, without any longitudinal joint, in the same way that tyres were already rolled out of a solid piece of metal without any weld.

He agreed with the statement made in the paper as to the corrosion being much more serious below the water line than above; but there were also certain places above the water line in locomotive boilers, where he had observed the effects of corrosion

to be particularly marked, and these were along the top corner of the back plate of the firebox shell, and at the angle-iron joint round the base of the steam dome. In both of these places he had found a considerable grooving in several boilers that he had examined; and it would be remembered that in the case of a recent explosion of a locomotive boiler on the Metropolitan Railway it had been found that the steam dome had been blown off, which no doubt was due to corrosion having taken place round the base of the dome, the mechanical action of the bending of the plates under pressure being concentrated at that part in consequence of the hole cut out for the steam dome.

Mr. F. W. Webb remarked that, in reference to the working pressure employed in locomotive boilers, the pressure in the locomotives on the London and North Western Railway was limited to 120 lbs. per square inch, and that had been the limit for many years past. The plan that had been long adopted on the same line for partially obviating the defects of the ordinary lap joints had been the telescopic form of boiler, in which the circumference of the successive plates was smaller towards the smokebox end of the barrel, each successive plate being put inside the preceding one, so that the strain was more nearly in the line of the plates, though not entirely so; and by this means the bending action upon the transverse circular lap joints was considerably [redacted]

so much to corrosion, he thought, as to the severe bending strain thrown upon that part, whenever the firebox end of the boiler was not left perfectly free between the frames so as to allow for expansion and contraction. In the case of six engines that had been handed over to the London and North Western Railway from another line, the plates were observed to appear much corroded at this point, and became worn through after three years' longer working, and the wear could not be explained at the time; but in repairing the engines, the firebox end, which had previously been rigidly attached to the frames, was left free to slide, and after that there was no further difficulty from corrosion at this part of the boiler.

The Chairman enquired whether any trial had been made to ascertain what would be the extent of corrosion in a boiler that was not at work, leaving the boiler full of water for a length of time and using it in fact merely as a tank, and whether the corrosion would then occur at the same places where it was now found in the boilers at work.

Mr. F. W. Webb did not know of any experiment of that sort having ever been tried; but it was not likely that any grooving at the joints would take place when the boiler was not subjected to the mechanical action from the alternation of the pressure. In the locomotive boilers on the London and North Western Railway the present practice was to form each length of the barrel out of a single plate bent round into a complete circle, so as to have only a single longitudinal joint instead of two; and this joint was then turned to the upper side of the barrel, so as to be in the steam space above the water line, whereby they had now almost entirely got rid of the difficulty of corrosion along the longitudinal joint.

The corrosion over the general surface of the plates depended a good deal, he believed, upon whether the boiler was fitted with iron tubes or brass tubes, particularly where the water employed in the boiler had any acid properties. For in the case of locomotives running upon some parts of the Yorkshire section of the London and North Western Railway where the water was of a very acid quality, he noticed that in boilers having iron tubes it was found

the general surface of the plates was not injured, on examining them when the tubes were taken out after five or six years' work; but the corresponding boilers working under the same circumstances with brass tubes were found to have the plates very badly pitted all over, which was no doubt owing to some galvanic action between the brass and iron.

The injurious effects of straining in locomotive boilers by alternate expansion and contraction were plainly shown in connection with the use of the injector for supplying the feed water to the boilers. The injector being originally placed at the side of the firebox, delivering the feed water in at that part, it was found that the constant straining of the outside firebox plate, from the continued changes of temperature owing to the intermittent stream of feed water supplied by the injector, caused the plate in a short time to become nearly cut through at the bottom close to the foundation ring of the firebox. This was partly due however to want of proper management on the part of the enginedriver in regulating the feed according to the rate of evaporation in the boiler, so that he was continually turning the injector on and off; but with proper care the injector could be so regulated as to deliver a constant stream of feed water into the boiler, in which case the firebox plate was kept at a more uniform temperature, and did not become injured by straining.

[redacted]

In the testing of the strips of welded plate that were exhibited, the average breaking strain struck him as being much lower than might have been expected, considering that the thickness of metal at the weld was greater than in the body of the plate; and he had been surprised to find that so many of the strips gave way at the weld. He thought however that this might perhaps be attributed to the manner in which the strips were obtained for testing, being taken from the piece of plate cut out of the boiler across the weld to form the hole for the steam dome; and this piece of plate being bent to the circle of the boiler, it was possible that sufficient care might not have been exercised in flattening the strips before testing them, and the strength of the iron might have been injured in the straightening. He suggested that it would be well to try testing the strips in their original curved form, without flattening them; and he thought it would also be desirable to take strips of a greater width than only 1 inch, when a more satisfactory result would probably be arrived at.

Having seen the welded boilers described in the paper in all the stages of their manufacture, and having also seen them tested to a pressure as high as 200 lbs. per square inch, he had great pleasure in bearing testimony to the very capital job that was made by this mode of construction, and there was no mistake that they were first-rate boilers both in workmanship and strength; they were indeed the strongest locomotive boilers running at the present time. With regard to the proposed plan of making the rings of the boiler barrel each in a solid hoop without welding, he understood that some experiments had been already made for accomplishing this object; and he should be glad to know whether it was intended to roll the hoop in the same way that weldless tyres were rolled, or to draw it like a tube. There was not much probability he thought of the working pressure being reduced in locomotive boilers; for the great aim now upon the railways was to obtain increased engine power for drawing the increased weight of the trains and for attaining a higher speed. For these purposes increased pressure of steam was required and stronger boilers, and the boiler described in the paper was an important step in that direction.

Mr. W. NAYLOR observed that an important fact bearing upon the strength of locomotive boilers when under pressure of steam was that the tensile strength of the plates was greater at the temperature of the high pressure steam than when cold. Having had frequent occasion to test the strength of wrought iron plates and bars for the Great Indian Peninsula Railway, he had found that it was usual to wait till the iron was cold, under the impression that the test would otherwise not be a fair one; and he had accordingly tried an experiment with a piece of best Yorkshire bar iron in order to ascertain the difference of strength when the iron was exposed to about the heat of a locomotive boiler. The bar was 2 inches by 1 inch, or 2 square inches section, and was cut into three lengths; and the two end pieces being tested cold broke at 51 tons tensile strain or $25\frac{1}{2}$ tons per square inch. The centre piece was then heated red-hot, and was allowed to cool gradually until an alloy of lead and tin would only just melt upon it, showing that the temperature was about 350° Fahr. or about the temperature of 120 lbs. steam. At this temperature the bar required 61 tons or $30\frac{1}{2}$ tons per square inch to break it, showing a tensile strength 20 per cent. greater than when cold. It was also found that the heated bar did not stretch more than half as much as the cold bars before breaking.

Mr. W. S. LONGRIDGE remarked that, in respect to the proposed plan which had been referred to of making the boiler barrel solid [redacted]

completely worked out, the intention was to build up a cylindrical coil, welded in the same way that guns were now constructed, from a double coil made of bars about $2\frac{1}{2}$ inches square, having a 5 inch hole through the centre of the coil: this coil, after being forged and expanded in the usual way to 15 or 16 inches diameter of hole, to be bored and turned. The object of boring and turning was not only to ensure the soundness of the iron in the previous stages of manufacture, before the bloom was submitted to the final process of rolling, but also to allow of greater accuracy being obtained in completing the finished ring. This bloom of 16 inches inside diameter having then been subjected to a welding heat in the furnace would be taken to the rolling machine, and rolled out to 4 feet diameter. This process might be accomplished after a little experience as easily he thought for a boiler barrel as for a tyre; and though at first it was not intended to attempt rolling the hoops of a greater length than $3\frac{1}{2}$ feet, he considered that when this was successfully effected it would only be a question of strength and size of machinery to roll an entire boiler barrel of 10 feet length. The experiments he was making were with iron; but had it not been for the prejudice at present met with against the use of Bessemer metal or other homogeneous metal for boilers, he would at once have adopted these for carrying out this system of boiler making, being satisfied that they would ultimately supersede iron for the purpose.

One point which had not been touched upon in the very interesting paper that had been read was the question of single-rivetted or double-rivetted joints; and as he observed that in all the specimens of corroded plates which were exhibited the lap joints were single-rivetted, while the improved boilers with butt joints had the outside covering hoops double-rivetted, he enquired whether it was considered that the single-rivetting employed with the ordinary lap joints had anything to do with the grooving of the plates at the joints, and whether it was on that account that double-rivetting had been adopted in connection with the butt joints in the improved boilers.

Mr. W. Kirtley replied that the double-rivetting of the butt joints in the improved welded boilers had been adopted only for the purpose of ensuring greater strength at the joints; and he did not think that the use of double-rivetting instead of single-rivetting would make any sensible difference in the extent of the grooving by the corrosion in the case of the ordinary lap-jointed boilers, as the injurious springing of the plate under pressure would be little affected.

With regard to the strips of welded plate that had been tested for trying the strength of the welded joints, the straightening of these before they were tested had been done with special care, in order that the strength might not be injured; and he thought the results might be taken as fairly representing the strength of the welds.

The Chairman moved a vote of thanks to Mr. Kirtley for his paper and the valuable specimens exhibited, which was passed.

The following paper, communicated through Mr. Walter May, was then read:—

[redacted]

ON AN IMPROVED CONSTRUCTION OF LOCK AND KEY.

By Mr. J. BEVERLEY FENBY, of Birmingham.

Although the varieties of Locks have been exceedingly numerous, yet so seldom has any new principle of security been introduced, that if locks are divided into two main classes—firstly those with fixed guards, and secondly those with moveable guards—a brief examination of the principles of construction involved in a few locks of each class will be sufficient for the purpose of the present paper.

The simple *fixed-guard* or *warded* lock is so utterly worthless for security, no matter what amount of good workmanship be bestowed upon it, that it demands but short notice. It was contrived with the intention of making the passage to the bolt intricate; but it will be seen at once that this intricacy does not really offer any security. The wards of a lock are circular arcs of thin metal, so arranged as to require a key of peculiar pattern to pass amongst them, the shape of the cuts in the key being a section of the wards. To make a really complicated box of wards, and to cut keys which shall accurately fit their sweep, is a matter requiring considerable manual dexterity; and some warded locks are therefore expensive. But even with the best of them all that it is necessary to do for opening the lock is to take a blank key which will properly fit the keyhole, coat it with wax, and then inserting it in the lock press it round against the wards, which will cause them to leave an accurate impression of their section on the key. The parts impressed are then cut out with small files, drills, and saws, and the occasional use of fine cross-cut chisels. The key will then pass those wards which impressed themselves upon it; and if these are the only wards it will go completely round and open the lock. If there are

also other wards in addition, not brought up flush with the first wards, the key is waxed again and pressed against them, and then further cut out, as before. This process is evidently one of absolute certainty, and the key so made is in all respects as capable of mastering the lock as the original key.

These warded locks are however easily opened with merely a piece of bent steel wire, bent into such a sweep as will reach right round the wards instead of passing amongst them, thus escaping all chance of being obstructed by them. Such an instrument is called by burglars a "twirl." In Fig. 19, Plate 30, is shown the key of an elaborately warded lock, and in Fig. 20 is shown a picklock or twirl which will open the lock belonging to this key, or any other lock having wards of about the same outside dimensions.

The fixed-guard or warded lock was the one in general use in the middle ages; but amongst the second class, or locks with *moveable guards*, is found the most ancient lock in the world, the Egyptian Lock, which is shown in Fig. 13, Plate 30. A A is the body of the lock, through which the bolt B passes. The pins C C C, working in cavities in the lock, drop into holes in the bolt when the solid end of the bolt is projected into the jamb of the door; and the lock is then locked. In order to unlock it, the key D is thrust [redacted]

letter or figure and has a single slot on the inner edge; and these rings are separately turned round by hand, instead of being turned by the bit of a key, until the inside slots are all brought into one line, allowing the bolt then to pass. Such contrivances may however be considered more curious than useful, and the best constructions of them have been readily picked.

The next kind of lock is the Tumbler Lock, in which the bolt is moved backwards and forwards by the key as usual, but these movements cannot take place till a small lever with a stump on one side be lifted. This lever and stump form the tumbler, which is held down by a spring; and in the tail of the bolt are two notches, into one of which the stump fits when the bolt is shot, and into the other when it is withdrawn. All that is necessary to effect the picking of this lock is to lift the tumbler high enough for clearing the stump out of the notch, and then draw back the bolt. The tumbler may be lifted with one pick, and the bolt drawn back with another; but generally one pick will suffice for both purposes. As the tumbler only requires to be lifted high enough, and cannot be lifted too high, no nicety is needed in the operation of picking.

In the Barron Tumbler Lock the principle of double-action was introduced. In place of simple notches in the upper edge of the bolt-tail, a slot is cut out of the tail in the direction of the length of the bolt; and this slot is long enough to admit of the proper motion of the bolt while the stump of the tumbler is in the slot. The notches for the stump are cut out in pairs on both sides of the slot, exactly opposite to one another, and the spring of the tumbler presses the stump into the two bottom notches, while the key or pick has to lift it out. If however the stump be lifted too high, it enters the opposite top notch, and so stops the motion of the bolt. This arrangement effected an important advance in the art of security.

The next improvement was the Lever Lock properly so called, under which designation the majority of the modern locks may be classed. In lever locks the stump for preventing the withdrawal of the bolt is fixed on the bolt itself; and the levers are made with radial slots or "gatings" in them, to admit of the passage of the

stump in withdrawing the bolt. The same principle runs through all the very numerous varieties of lever locks, as regards their essential construction and action, their differences lying mainly in the addition of various ingenious contrivances for detecting attempts at picking the lock and for increasing the difficulty of access to the levers.

The principle of the lever lock is shown in Fig. 14, Plate 30. On the bolt B of the lock is fixed the stump S, a square-edged stud, which passes through a slot in each of the levers L; these are a series of plates having all the same external form and all working upon a common centre pin, and fitting in thickness the successive steps of the key, Fig. 15. A radial slot or "gating" G is cut in each lever to allow the stump S to pass when the bolt is withdrawn; and these gatings being cut in different positions in each lever, it is requisite before the bolt can be withdrawn in unlocking that all the gatings should be brought exactly under the stump, which is effected by the several steps of the key being made of the proper height to suit their respective levers.

In the actual manufacture of these locks, the key is first cut with an arbitrary division of the several heights of the steps; and each lever in succession being lifted by the key to its full extent, the gating G is then marked on the lever to correspond with the position of the stump S. On the accuracy with which the gating is cut to fit the stump depends the security of the lock from being opened either by picking or by a false key differing slightly from the original. A curved notch or "racking" R is made at the bottom of the gating, for the purpose of allowing the levers to be pressed back into their original position by the springs I when the bolt is withdrawn, as they would otherwise be retained in their raised position, and would then give by their inner edges a direct indication of the form of key required for opening the lock.

The celebrated Bramah Lock consists of a metal cylinder with a hole passing down the centre; and a number of slots are cut radiating outwards from the centre hole and running throughout the length of the cylinder. A groove is turned in the cylinder from the outside, so far as to cut a short distance into all the slots; and

into each slot a steel slide is fitted, having a notch cut in its outer edge, in such a position that when the slide is pushed in longitudinally to the proper distance the notch exactly corresponds with the groove in the cylinder. Into this groove fits an annular disc of steel, having nicks cut on its inner edge corresponding to the radial slots in the cylinder, and through these nicks the slides work freely. The annular disc is fixed securely in the external case of the lock; and the slides being held up by a spring, so that the solid part of each is in the nicks of the disc, prevent the cylinder from being turned round for unlocking the lock. In order to free the cylinder for turning, the slides must all be pushed in longitudinally to such an extent that their notches coincide exactly with the annular disc; the slides can then pass round upon the disc, allowing the cylinder to revolve and move the bolt. For pushing the several slides in to the respective depths required, a tubular key is used, having longitudinal slits cut in its end, the length of the slits corresponding inversely to the depth to which the respective slides have to be pushed. Should any one slide be pushed too far or not far enough, its notch will not coincide with the disc, and it will therefore prevent the cylinder from being turned.

The Bramah Lock was an admirable contrivance with remarkably beautiful mechanism contained in a small compass; and since its invention there have been several ingenious modifications of the same principle in different radial locks, such as the Yale Lock, in which the slides move radially instead of axially. One advantage in these radial locks is the greater difficulty in copying the keys, in comparison with the flat keys of ordinary lever locks: this difficulty however is not an insurmountable one.

A very ingenious addition was made to the action of the lever lock in Newell's American Lock, which was shown in the 1851 Exhibition and described in a paper at a former meeting of the Institution (see Proceedings Inst. M. E. June 1851, Page 16). In this lock the several steps of the key were made each of a separate piece, excepting the first and last steps which were solid as usual but had no action on the levers; and the intermediate steps were

secured in their places by a screwed pin passing through them and through the two fixed steps. After unlocking the lock, the key could be changed by altering the relative positions of the moveable steps; and the lock was so constructed that it admitted of being locked the next time with the altered key, while only that same arrangement of key would then unlock it again. This was effected by having, instead of the ordinary solid stump, a compound stump, in which was a separate piece for each lever; these component parts of the stump were lifted up with the levers in the act of locking the lock, and being held in their raised position by a paul which engaged in a rack formed in the back of each, the compound stump was thus made an exact copy of the arrangement of key used in locking. As the levers fell back on withdrawing the key, nothing but the same arrangement of the steps in the key could bring them again to correspond with the several parts of the stump for unlocking.

The important point gained in this lock was that no copy of the key was available for opening the lock, unless taken from the very arrangement of key with which the lock was last locked: the intention being that the pieces of the key should be changed immediately after locking, their position only being noted for restoring the key to the form required for opening the lock again; consequently in the interim any wax impression taken from the key would be useless. This lock, though certainly a remarkable triumph [redacted]

applying picklocks, yet the keyhole was still left open at other times for the action of picklocks; and the use of a key requiring to be unscrewed and screwed together again every time that the lock was either locked or unlocked involved a serious practical objection.

Though locks such as those already referred to exhibit great dissimilarity of construction, yet there is one point in which they all agree, and that is in the possession of a direct passage from the outside to the works. Although various locks have been devised with the object of having no direct passage to the works from the outside, one consideration shows the inevitable existence of such a passage: namely that without it the key could not possibly at one and the same time touch the hand of the operator and the works of the lock. It therefore follows that any instrument which can pass in the same space as the key may be brought to bear on the works, whatever may be their construction.

It can now be shown that, if picking instruments are thus brought to bear on the works through the keyhole, there is a regular tentative system whereby the picking of any lock with an open keyhole can sooner or later be effected. The mode of operation is in its chief features the same for all moveable-guard locks. Taking as a single example the Egyptian lock shown in Fig. 13, to pick this lock the following method is used. A piece of wood or metal is taken similar to the key D, but without the pins E; and wax or clay having been spread on the upper surface, it is put into the lock and pressed up against the holes C, so as to take an impression of their position. Corresponding pins are now fixed in these places, and the key so made is again introduced into the lock; and by the exercise of just so much skill as is required to lift the pins C free from the bolt, without lifting the key so far as to cause its own pins to catch in the upper case A, the lock is picked. The pins on the key may then be regulated to the proper height, so as to make it impossible to lift up too high with them; and when this is done the counterfeit key is in all respects as good as the one properly belonging to the lock. If the pins put on the counterfeit

key for the purpose of picking the lock be made of some substance having sufficient tenacity to lift the lock pins and draw the bolt, but not strong enough to resist the shearing action between the bolt B and the case A, then however high the lock pins C may be lifted by the counterfeit the bolt will yet be withdrawn, and the precise length of the pins on the key will at the same time be obtained.

The picking of this elementary moveable-guard lock comprises the principles of the art of lock-picking; and to apply these principles to the picking of a lever lock, the following variation of the process is put in practice. Reverting to the lever lock shown in Fig. 14, if by any means except the use of the key the gatings G can be brought into such a position as to allow the stump S to pass through them, that constitutes picking the lock. This has been performed with the simple tool shown in Figs. 16, 17, and 18, which consists of a tube F made to fit upon the drill pin of the lock; and on this tube fits another external tube H, which turns and slides easily on the inner tube F, but with perfect steadiness. Each tube has a projecting step at the extreme end, corresponding to a certain extent with the steps of the key, the difference lying only in the length. With the step on the inner tube F the bolt B, Fig. 14, is pressed back so as to feel the stump S against the levers L, and a constant pressure is kept upon them by the stump by means of the weight W, Fig. 16, suspended from an arm on the inner tube F.

actually prevent it; for locks with sixteen levers having false notches as well as other improvements have been picked.

This was the mode of picking so successfully shown by Mr. Hobbs, who at the time of the 1851 Exhibition opened in this manner a lever lock of one of the best makes. A similar method has been used with locks made on the Bramah principle, only that in this case the radial slides have to be pushed in, while a slight twist of the cylinder, to make the slides bind against the guard-plate, supplies the place of the pressure put upon the bolt of the lever lock; and in this way a Bramah lock was also picked by Mr. Hobbs. In the radial locks the only variation is in pushing the slides radially instead of axially, the cylinder being slightly twisted at the time as in the Bramah lock; and a lock with as many as 40 radial slides has been picked. There are also additional modes of operation in lock-picking, such as smoking the working parts with a taper, so that the right key when used shall indicate the gradations of its action on the works, which are afterwards examined by a small mirror introduced through the keyhole. Enough has however been stated to show that there is nothing to prevent attempts at picking from being made on any lock having an open keyhole, nor any certain means of ascertaining whether at any time such attempts are in progress.

The other mode of attacking a lock is by taking an impression of the true key and making a counterfeit key from it. As a remarkable instance of this method may be named the case in which two of the best lever locks were opened a few years ago by Agar and his confederates, and £12,000 worth of gold was stolen, weighing upwards of 200 lbs., while in transit on the South Eastern Railway from London to Paris. In this important robbery, which took place on 15th May, 1855, the gold was sent in three boxes, iron-bound and sealed, and packed in a bullion safe, which was secured by two new locks of the best and most improved make, duplicate keys being kept at the London and Folkestone stations. By the collusion of two of the railway officials wax impressions of the keys for the two locks were obtained, and counterfeit keys made from them; but it was found requisite to make no less than seven trials

of these counterfeit keys before they could be sufficiently perfected to open the locks. The only means of making these trials was by travelling with the bullion safe in the van, by collusion of the guard of the train, at the same time running the risk in each trial of creating a fatal suspicion by over-lifting the detectors in the locks. The whole was however ultimately accomplished with complete success, and the robbery effected, although only after a period of several months' perseverance, to which the thieves were stimulated by the very large amount of the prize to be obtained.

From the foregoing observations it is evident that there are two important defects in the principle of the previous lever locks, which being defects in principle are fatal to their security: namely the means of access to the works of the lock through the keyhole, allowing of a series of attempts being made to open the lock by picking instruments; and also the facility afforded for repeating the trial of a false key made from a wax impression of the true key, and thus perfecting it by successive alterations after trial. In consequence of the possibility thus allowed of making these successive attempts either by picking instruments or by a false key, it has been shown by the cases that have occurred of locks of the best makes which have been falsely opened, that, however numerous and complicated may be the secondary impediments introduced into [redacted]

lie under the levers L and cylinder C is removed, as seen in Fig. 6, Plate 27, and replaced by a separate flat plate or stump-bolt, carrying the stump S. This stump-bolt has a projection K upon it, let into a recess in the tail D of the main bolt, but with $\frac{1}{10}$th inch vertical play in the recess. A spring in the tail of the main bolt presses the stump-bolt downwards, keeping the stump S in the notches of the levers L, as shown in Fig. 1. The stump-bolt can thus descend $\frac{1}{10}$th inch at first without moving the main bolt, and this amount of vertical movement is sufficient to carry the stump in and out of the notches in the levers; but the stump-bolt cannot descend further without taking the main bolt with it.

Immediately in front of the bolts comes the fixed plate H H, in which is cut the cam groove shown by the dotted line J J; and also the vertical slot E for the pin P to work through, together with another vertical slot in which the stump S fits and works. This plate carries the centre pin U on which the levers L turn. The levers are six in number, though any other number may be used; and they occupy collectively 3-8ths inch thickness. In front of the plate H is fixed the guard A, which is made of iron or steel, and has the brass cylinder C ground into it. The guard is made a shade thicker than the levers L, in order to prevent the back plate H and the corresponding front plate from being so tightened on the levers as to impede their freedom of movement. The cylinder C is the same thickness as the levers, excepting the centre boss F, which projects from the back of the cylinder and works in a bearing in the back plate H, and also projects in front through the thickness of the two front cover plates. The small keyhole in the centre of the boss goes only a short distance into the cylinder C, being merely for the purpose of enabling the stem of the key M, Fig. 8, to turn the cylinder; the bit of the key is a separate piece N, which is inserted through a separate keyhole into the radial slot of the revolving cylinder C, as shown at N in Fig. 1.

This radial slot is cut in the side of the cylinder C that is furthest from the levers when the cylinder is in the position shown in Fig. 1; and in the slot fits the slide block R, which is a steel block having a pin projecting on each side. The back pin enters

the guide groove J J in the back plate H, as shown by the dotted line, and the front pin enters the corresponding guide groove in the front cover plate which is shown removed. The back pin of the slide block projects through the back plate H, as shown in Fig. 7, and works in the cam groove O in the tail of the stump-bolt S, Fig. 6, which is so shaped that as the slide block travels round the guide groove J J, shown by the dotted lines, it moves the stump-bolt vertically as may be required according to the position of the bolts and levers.

In the position of the lock shown in Fig. 1, the bit N has been inserted into the vacant space of the radial slot in the cylinder C, in front of the slide block R. The size of this vacant space is 3-8ths inch long by 1-8th inch wide and 3-8ths inch deep; and in the two front cover plates of the lock, and also in the door to which the lock is attached, a hole is made of the same shape. In the door there is no bearing for the centre boss F, but only a small keyhole corresponding in size with that in the boss F for inserting the stem of the key.

In the position of the parts shown in Fig. 1, it will be seen that the levers L are held pressing down against the circumference of the cylinder C by their springs I bearing against the pin P. In this position also the bolt spring between the main bolt and the [redacted]

the cylinder is brought opposite to the aperture, which is thereby completely closed against the insertion of a picking instrument. This construction accordingly not only precludes the possibility of opening this lock with an ordinary key, in which the part that acts on the levers is attached to the stem of the key, but it also renders it an absolute impossibility to introduce a pick of any form, as nothing can reach the levers L except a detached piece of such a size and shape as to be capable of travelling round in the vacant space left in front of the slide block R in the radial slot of the cylinder C.

For the purpose of unlocking the lock the bit N, Fig. 9, is used. This bit is of such a size as to fit into the vacant space of $\frac{3}{8} \times \frac{3}{8} \times \frac{1}{8}$ inch in the radial slot of the cylinder C; and the indent at V is merely for the purpose of ensuring the insertion of the bit in the right direction, the external aperture for the bit being made with a corresponding projection to fit the indent in the bit. This bit being inserted through the aperture in the door is pushed in by means of the key stem M, which is flattened on two sides for that purpose, as shown in Fig. 8; and the bit is thus pushed home into its place in the radial slot of the cylinder, as shown at N, Fig. 1.

The key stem M is now inserted into the centre keyhole F, and the cylinder is turned round by it in the direction shown by the arrow, carrying round the slide block R and the bit N. The slide block R while moving through the concentric portion at the commencement of the guide grooves J J does not affect the bit; but by means of the cam groove O in the tail of the stump-bolt, Fig. 6, it moves that bolt so far as to lift the stump S completely out of the notches in the levers L, which are thereby left free to be raised. On continuing to turn the cylinder C the eccentric part of the guide grooves J J causes the slide block R to move outwards along the radial slot, pushing the bit N before it; and the bit is thus made to project beyond the circumference of the cylinder, which it can then do, being no longer confined by the guard A. The further projection of the bit as the cylinder revolves causes the steps in the bit to lift their respective levers; and the steps in the bit are so arranged that, when the cylinder arrives at the position

shown in Fig. 2, all the gatings G are brought simultaneously opposite the stump S, which is instantly shot down through the distance of the $\frac{1}{10}$th inch play by the bolt spring. The bit N remains in contact with the extreme part T of the levers while the stump S is entering the gatings, the action of the bolt spring being so rapid that the bit cannot move through any appreciable distance during the time.

In other locks a spring action of this kind would greatly facilitate the picking, inasmuch as it would afford the gentle uniform pressure desired upon the levers, which is given by the weighted arm F in the picklock previously described, Fig. 18. In other locks therefore the bolt is caused to move and the stump to enter the gatings by the direct contact of the key with the bolt, instead of by a spring; but as the key, while moving the stump into the gatings, is also altering its position under the levers, a slight tremulous motion of the levers is thereby occasioned, which no care in manufacture can obviate. This tremulous motion is aggravated by the circumstance that, as the keyhole is open to inspection, it is necessary to make all the levers fit flush with one another when down, in order to avoid affording any clue to the shape of the key from the positions of the levers; but as the various steps of the key, being of different lengths, describe different arcs, the curves of the levers when raised are of necessity in error to them all. The result of these combined

[redacted]

in Fig. 3, Plate 26, the slide block R has pushed the bit completely out of the radial slot, and the bit falls down as shown in Fig. 3, and drops through a hole into the inside of the safe that is locked. At this point the back pin of the slide block comes in contact with the lower side of the cam groove O in the stump-bolt, Fig. 6; and by turning the cylinder C onwards to the position shown in Fig. 5, the withdrawal of the bolt B is completed, bringing the parts into the position shown in Fig. 5. In these drawings only one lever L is shown; but there are altogether six levers, as shown in the sectional plan, Fig. 7. The pin P is fixed in the tail D of the main bolt, so as to travel with the bolt; and by this means the springs I are released from strain, as shown in Fig. 5, as soon as the bolt is withdrawn.

From the nicety with which the various parts of this lock are constructed, it is evident that the levers must be very accurately lifted by the bit of the key in order to withdraw the bolt; and therefore any error in the bit, such as would occur with a false bit, will effectually prevent the lock from being opened. This may be illustrated by supposing the false bit to be so close an imitation as to have five of its steps absolutely correct, and the sixth only slightly wrong: though it is almost impossible that such a near approach to correctness could be attained in practice. The counterfeit bit being inserted in the lock and the cylinder turned round, all will go on the same as with the true bit, up to the time when the false bit reaches the point T of the levers, as previously shown with the true bit in Fig. 2. Here a change of action takes place; but what is the nature of the change the operator has no means as yet of ascertaining. In the case supposed, where five of the steps in the bit are right but the sixth is wrong, the gating of the sixth lever does not precisely coincide with the others nor with the stump S; and the consequence is that, at the critical moment when the stump ought to spring into the gatings and hold back the levers from falling forwards, it will be prevented from entering the gatings, owing to the entrance being partly blocked up by the one lever which stands more or less across it.

The fact however that the stump cannot enter the gatings does not become known to the operator until the cylinder C has been turned further round so as to bring the slide-block pin in contact with the lower side of the cam groove O in the stump-bolt; and before this point has been reached the false bit has already passed clear of the levers, which not being retained by the stump are instantly thrown forwards again by their springs, and locked in their original position by the stump entering the notches. At the same time the false bit has dropped into the inside of the safe in the same manner as the true bit, as shown in Fig. 4.

Hence a person putting a false bit into one of these locks will not only infallibly lose it at the very first trial, but will do so without gaining any information as to the nature of its inaccuracy; for as the gatings of the levers cannot be seen or felt, all that can be told about the action of a false bit is that it has failed to open the lock. In fact a counterfeit bit passes under the levers and through the lock just like the true bit; and it is only the stoppage afterwards met with of the bolt that indicates the failure of the false bit, which is by that time gone beyond recovery. Whatever amount of labour therefore may have been spent on the fabrication of a counterfeit bit, this bit can only be tried once, so that no alteration can afterwards be made in it.

Nothing that can be inserted into the radial slot of the cylinder C [redacted]

to the saw by the slide-rest B. The bit I is fixed in the holder C, which rocks upon a centre, so as to give the required curvature to the edge of each step in the bit when cut by the saw, as shown in the full-size section of the bit-holder, Fig. 11. The adjustment of the depth of cut is effected by the set screw D upon the slide-rest coming up against the eccentric ring E upon the bed of the slide-rest; this ring is turned round by hand, and set to sixteen different positions by means of the catch-pin F and the sixteen holes on the circumference of the ring, allowing of sixteen different depths of cut. The lateral adjustment for the pitch between the successive steps of the bit is effected by the two bed-screws G G acting on the slide-rest B, having a dividing plate on the head and such a pitch of thread that one turn of the screws traverses the slide-rest through the exact distance of one step in the bit. The occurrence of any play or backlash is entirely prevented by having the screws placed one at each end of the slide-rest; so that by slacking back one screw through one or more turns and then advancing the other through the same number of turns, the slide-rest is always held with perfect steadiness between them, filling exactly the space between the ends of the two screws.

The number of changes admissible in this key-cutting machine, if used for making keys for locks having six levers, is the number of permutations that sixteen terms are capable of when taken six together, which is upwards of sixteen millions. Some of these changes are so slight that too great accuracy of workmanship would be required to make the locks accordingly; but of those changes that differ from one another so far that no lock could be opened by any other than its own key, more remain than could be used up by all the locks in the world.

The writer may observe that it was the study of the circumstances of the great gold robbery previously referred to, and of the various modes of picking locks, which led him to turn his attention to the achievement of what had been so long and perseveringly sought after, namely an unpickable lock. The principle of a detached bit has been previously tried, in so far as that locks have been made in which the bit of the key was deposited in the lock by unscrewing

the key stem, and then withdrawn by screwing in the stem again. But inasmuch as the detached bit, even though it failed to open the lock in the case of a counterfeit key, could always be brought back again to the keyhole and removed, this admitted of a repetition of attempts with successive alterations of the one counterfeit key, without the certainty that any warning would be given by the lock of such attempts having been made.

In another still more complicated lock with a detached bit there were two keyholes, into one of which the bit of the key was put, and the stem being then unscrewed from the bit was put into the second keyhole and turned round so as to close the first keyhole over the bit; a separate handle was then turned to work the lock, six separate operations being required for either opening or closing the lock. Further a kind of retainer has been attempted by so arranging the lock that, if any key was put in but the right one, it was held in the keyhole in such a manner that it could never be got out. In this case however, if the false key would not open the lock, neither would it let even the right one do so, and it would be necessary to break open the door secured by the lock.

In the new lock described in the present paper the special points that have been aimed at are the following:—

Firstly, in no position of the lock is there any access to the [redacted]

gunpowder in the keyhole, the only openings from the outside being parallel at their sides, and not communicating with any portion of the interior of the lock; and the simplicity and solidity of construction are such that the revolving cylinder is made practically air-tight within its bearing. This effectually prevents all attempts to open the lock by picklocks, and leaves no alternative but the attempt to make a sufficiently accurate copy of the true key.

Secondly, as no clue whatever can be obtained from the outside of the lock respecting the key required, the attempts upon the lock are thus limited to the chance of obtaining a wax impression of the true key. The difficulty of making a counterfeit key sufficiently correct by this means for opening one of the best of the previous constructions of lock is very great; but in the new lock this difficulty is greatly increased by the fact of the levers remaining absolutely stationary while the stump enters the gatings, in consequence of which the gatings are made so close a fit to the stump that an exceedingly minute error in the lifting of any of the levers is sufficient to prevent the lock being opened. This extreme delicacy of construction can be carried out practically without objection in the new lock, because there is no possibility of putting a strain from the key upon the stump, so as to cause injury by forcing it at the moment of entering the gatings; for the only force acting upon the stump at that time is the uniform pressure of its own spring. In addition to this source of increased safety, there is the still more important circumstance that only a single trial can be made of each counterfeit bit; because, if carried forwards far enough to try its effect in opening the lock by passing the levers, the bit is inevitably lost by falling through the lock and inside the door. Thus not only is all chance prevented of a second trial with the same key, but the bit retained inside the door gives warning of the attempt having been made, and shows how near the counterfeit key has approached to the original. The numerous cases that have occurred of attempts to open locks by counterfeit keys, such as the remarkable instance previously referred to, show that even with the most practised hands it is next

to impossible to make from a wax impression a key that will serve for opening a good lock the very first time it is tried; and the striking importance is therefore seen of this arrangement in the new lock, which prevents more than a single attempt being made with a counterfeit.

Thirdly, another advantage to be named in this lock is that the stem alone of the key is required to lock it, but it can only be unlocked by the complete key. The stem therefore can be left by the principal of an establishment for locking up by a subordinate; but the bit, which is the essential part of the key required for opening the lock, need never be used or seen by any one but the principal himself. As the hole in the external door-plate for the stem of the key has a notch on one side only to admit the key-stem, and the cylinder is prevented from making a complete revolution, the stem of the key cannot be withdrawn from the lock except when the bolt is shot; so that its absence from the keyhole serves as a proof that the bolt is shot.

Fourthly, one other advantage in this lock is its simplicity and solidity of construction. It contains no more parts than the simpler forms of lever lock having the same number of levers, and the total number of separate pieces in the complete lock is only sixteen. The principle of security therefore upon which the new lock is constructed avoids entirely the complications and the delicate and [redacted]

was practicable in the best handwork from a wax impression. He also exhibited the key-cutting machine, employed for cutting the bits; and also a set of burglar's tools employed for drilling into the door of an iron safe sufficiently for breaking open or removing the lock, showing that the hold required for giving the cutting pressure upon the powerful drill employed for the purpose was obtained by a steel cross piece inserted into the keyhole and turned at right angles, so as to hold across inside the lock; but in the new lock, as the keyhole had no opening into the lock and only a slight shoulder on one side, no means were afforded for obtaining the required hold for the drill.

A specimen was also exhibited, lent by Messrs. Hobbs and Co., of one of the permutating locks, similar in construction to the one shown at the former meeting of the Institution (see Proceedings Inst. M. E. 1851, Plates 33 to 35), having the key composed of a number of separate bits, the arrangement of which upon the key stem could be varied at pleasure, while the lock could only be unlocked with the particular arrangement by which it had been locked. The present lock had also in addition the subsequent improvement referred to in the paper, the stem of the key being removed from the bits during the operation of locking and unlocking.

The Chairman remarked that the paper just read gave a very excellent and clear description of the detailed working of the new lock, and he thought this construction of lock was a most valuable one, as affording real security against all fraudulent attempts. He enquired whether there would be any possibility of tampering with the lock by examining it upon the inside of a safe door, whenever the door might happen to be left unlocked.

Mr. Fenby replied that there was no means of tampering with the lock from the inside of the door, as the two keyholes for working the lock were only in the front face of the door, and the lock was all closed up on the inside of the door, excepting the hole through which the bit was allowed to drop out; but this would be useless for the purpose of tampering with the lock, as the bit dropped down a tube leading to the bottom of the door, through which no examination of the lock could be successfully made.

The CHAIRMAN enquired whether there was any provision against the bit being accidentally locked up inside the safe, in which case it appeared the lock could not be opened again.

Mr. FENBY replied that the owner of the safe must of course be careful after unlocking the safe to take the bit out before locking it again, otherwise there would be no means of opening the lock afterwards with that key. As a precaution however against any such accident each lock was provided with three bits, all duplicates, one of which would be kept in the pocket for use, while the two others would be preserved in a place of safety for the chance of any such contingency. Moreover in most of the safes fitted with these locks, the tube through which the bit dropped had been made of such a length as to carry out the bit on opening the door, dropping it into a small tin tray outside the safe; and by this means the accidental locking in of the right bit was rendered impossible. One of the advantages of the new lock was that the stem of the key was not required to be kept constantly in the possession of the owner, but it might be left in the lock, as the bit alone was the valuable part of the key; and as the bits were of such small size and convenient shape, a number of them might readily be kept in the pocket by a person having charge of a number of safes, without the inconvenience attending a large bunch of ordinary keys. In the case of an attempt being made to open the lock with a

Mr. W. S. Longridge observed that the inconvenience that had been alluded to with the new lock, of accidentally locking up the bit inside the safe, was no greater than occurred with an ordinary safe lock if ever the key was accidentally lost; in either case, unless the precaution was taken of keeping a duplicate in reserve, it would of course be necessary to have the safe broken open.

The Chairman enquired how the ideas had been arrived at of separating the bit from the key, and of preventing all access to the works through the keyhole, and also of retaining the bit inside the door after any attempt at unlocking.

Mr. Fenby replied that his attention had in the first instance been attracted to the subject of the picking of locks as a mechanical problem, and he had found that there had hitherto been no principle in lockmaking which could effectually baffle persevering attempts at picking. For although there were certain complicated constructions of locks, having many points of excellence, they had all yielded in time to the picking instrument in clever hands; and it must be remembered that any individual lock when once constructed remained stationary as regarded subsequent improvement, whereas the art of picking that lock was continually progressing towards success, with all previous constructions of locks, and it was clear therefore that the lock must ultimately be defeated. He had been further stimulated in the investigation of this subject by the occurrence of the great gold robbery referred to in the paper; and the circumstance which had struck him most forcibly in connection with that robbery had been that locks of the best make hitherto known had admitted of seven successive trials being made upon them without detection, each trial furnishing the information for further perfecting the counterfeit key, until the locks were at length opened.

These considerations had led him to the conclusion that two points were established and were required to be kept in view for the construction of any lock that should be really secure against fraudulent attempts. The first point was that wherever a man could get instruments into the lock he could ultimately solve any problem laid before him by the maker of the lock, as the lock when

once made could be tried any number of times if an instrument could be got into it at all. Hence he had concluded that it was requisite for all access to the interior to be cut off, so as to preclude all possibility of getting a picklock in; and this was accordingly accomplished by adopting the plan of separating the bit from the stem of the key. The second point established was that it was necessary to prevent the possibility of making a succession of trials with the same counterfeit key; and it had then struck him that, if the bit of the key were arranged to drop inside the safe in unlocking, there would be no means of going on gradually improving and touching up the counterfeit from the results of previous trials, as the false bit would be irrecoverably lost in the very first attempt, without furnishing any clue whatever as a guide for alteration in a subsequent trial. The first lock that he had invented for meeting the requirements thus pointed out had been made with a solid block having a tunnel through it, but involving the same principle of retaining the bit of the key and keeping the levers inaccessible from the outside. Subsequently however he had abandoned that construction and produced the new lock shown in the drawings, having the revolving barrel with radial slot.

The CHAIRMAN proposed a vote of thanks to Mr. Fenby for his paper, which was passed.

PROCEEDINGS.

31 July and 1 August, 1866.

The Annual Meeting of the Members was held in the Lecture Theatre, Mechanics' Institution, David Street, Manchester, on Tuesday, 31st July, 1866; Joseph Whitworth, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected :—

MEMBERS.

William Adams,	London.
George Armstrong,	Wolverhampton.
William Carpmael, Jun.,	London.
Henry Chapman,	Paris.
Edward Freer Daniel,	Shrewsbury.
Joseph Beverley Fenby,	Birmingham.
Charles John Galloway,	Manchester.
William Ireland,	Manchester.
Alban Meredith,	Dalton-in-Furness.
Alfred Sacre,	Sheffield.
Joseph Smethurst,	Guide Bridge.
Eli Spencer,	Oldham.
John Classon Stephens,	Dublin.
John Stevenson,	Middlesbrough.
Henry Wren,	Manchester.

ASSOCIATE.

RICHARD LEWIS WHITE, . . . Swindon.

GRADUATES.

JAMES BUTLER, ... Manchester.
THOMAS SNOWDEN BUTLER, . . Leeds.

The following paper was then read:—

ON THE PROOF OF GUNS BY MEASUREMENT, WITH DESCRIPTION OF THE INSTRUMENT EMPLOYED.

By the President, JOSEPH WHITWORTH, Esq.

Many rifled Guns have doubtless been permanently injured by having been proved with excessive charges. The writer's object has been to ascertain what amount of charge any particular description of gun will bear, without a permanent alteration of its parts; and by the use of his Contact Measuring Instrument for this purpose a difference of one ten-thousandth part of an inch can be detected.

Before commencing the proof an exact measure is taken of the bore of the gun opposite the centre of the powder charge A, Fig. 1, Plate 31; and also opposite the centre of the projectile B. A shot is then fired with a powder charge somewhat smaller than that intended when using the proper weight of projectile. The bore is again measured at the same places, and also near the base of the shot, which will be found to have enlarged the most; and this enlargement takes place more or less even with what may be considered a legitimate charge, and is altogether independent of the general overstraining and enlargement produced by an excessive charge.

As a general rule the writer has found that, as regards accuracy of fire and penetration, the best length for a solid projectile is three diameters; and the total weight of powder that the gun can wholly consume before the shot has left the gun is about one seventh of the weight of this projectile. Applying these proportions to the 600 pounder gun now in our service, which has a bore of 13 inches, it should fire a 990 lbs. shot and consume 141 lbs. of powder; while the American gun of 15 inches bore should fire a 1522 lbs. shot with 217 lbs. of powder. It thus appears that

the bores are too large in the above cases; and therefore the guns themselves will be found totally inefficient when they have to contend with others of smaller bores using the proportions of powder and shot that have been named.

The Instrument designed by the writer for the proof of guns by measurement is shown in Figs. 4 to 6, Plates 32 and 33. Fig. 1 is a longitudinal section of a 7 inch gun, the dotted lines showing the measuring instrument as when placed in the bore for measuring. Fig. 4 is a longitudinal section to a larger scale, and Fig. 6 a transverse section of the gun and the head of the measuring instrument drawn half full size, showing the three sliding feelers and contact pieces by which the measurement is effected.

The long stem of the measuring instrument is composed of two tubes, which for strength and lightness are made of steel. The outer tube C is attached to a brass head, which has three radial arms DDD. Into grooves in these arms are accurately fitted the three sliding steel feelers F, which are secured in their places by a covering plate. The inner ends of these feelers work in three inclined dovetailed grooves in the wedge piece G, which is attached to the end of the inner tube E; their outer ends, which come in contact with the sides of the bore of the gun, have pieces of hardened steel screwed on in order to reduce the wear to a minimum, and render [redacted]

inclination of 1 in 20, one division of the micrometer wheel K causes the feelers F to move out or in through ·0001 inch or 1-10,000th inch; and an enlargement of the bore to this minute extent of 1-10,000th inch is decidedly felt by moving the rod and feelers backwards and forwards a short distance within the bore of the gun. The rod C is supported at the muzzle of the gun on a grooved brass pulley L, Fig. 4, which facilitates its free movement backwards and forwards in the bore of the gun. In order to measure with the greatest accuracy, it is necessary that the bore of the gun be carefully washed out after each discharge, as any fouling or particles of grit left in the bore would interfere with the requisite measurement. With care a skilful manipulation may always detect a difference of only one ten-thousandth part of an inch.

During the competitive trials of the special committee at Shoeburyness in 1864 the writer designed this measuring instrument for ascertaining for his own information the alteration which took place in the bore of the 70 pounder gun under trial. The measurements, which were carefully taken at different times during the firing of nearly 3000 rounds, showed that the enlargements of the bore with successive charges of 10 lbs. of powder and 70 lbs. shot were regular, and were due entirely to wear of the gun in the powder chamber; but when the powder charge was increased, and a large air space left, the gun being loaded each time with a number of shot, the enlargement of the bore was so rapid that a continuance of those charges must have led to the destruction of the gun, as the enlargements showed that a permanent set must have taken place at every discharge.

In the first 2886 rounds the total enlargement in diameter at the base of the shot was ·0198 inch, as shown in the accompanying Table. In the next 50 rounds, 40 were fired with heavier shot, namely 20 rounds with 140 lbs. and 20 with 280 lbs., and an air space of 12 inches was left between the powder and shot; the further enlargement of the bore at the base of the shot was ·0170 inch, showing that nearly as much total enlargement was caused by these 50 rounds as by the previous 2886 rounds. The

last 15 rounds, fired with still heavier shot varying from 350 to 490 lbs., and 5 of them with an increased powder charge of 15 lbs., produced a still further enlargement of ·0157 inch, being nearly equal to that of the 2886 or the 50 rounds.

The total enlargement of the bore at 35 inches in from the muzzle after firing 2886 rounds was ·0018 inch.

Trials of 70 pounder Whitworth Gun.

Weight of Powder.	Weight of Shot.	Air Space.	No. of Rounds.	Enlargement of Bore.
Lbs.	Lbs.	Inches.		Inch.
10	70	—	992	·0062
10	70	—	1036	·0054
10	70	—	858	·0082
		Total	2886	·0198
10	70	12	10	
10	140	12	20	
10	280	12	20	
		Total	50	·0170
10	490	12	10	
15	350	6	1	
15	420	6	1	
15	490	6	3	

Mr. W. Fairbairn observed that the measuring instrument which had been described appeared well adapted for the purpose intended, and afforded the means of measuring with extreme accuracy the exact enlargement produced in the bore by a number of discharges. The use of the measuring instrument in the trials described in the paper now showed that nearly as much damage was done to the gun by enlargement of the bore in 50 rounds with a very heavy charge as in 2886 rounds with the more moderate charge that the gun was intended to carry; and it therefore appeared, particularly in the case of the heavier charges, that it was merely a question of time how long the gun would stand the repeated discharges before becoming so much damaged as to be in danger of bursting. The result thus arrived at by applying the system of measurement to the proof of guns was a confirmation of what was observed in other cases in connection with the strains of materials; for in regard to the limit of elasticity in different materials, although this was intended to mean such a limit of strain that any lower strain would not produce a permanent set in the material, yet he had found that a strain amounting to only one tenth of that limit, when repeated often enough, led ultimately to fracture; and he therefore inferred that, even in the case of still smaller charges, the gun must ultimately be destroyed by repeated discharges, even supposing it should stand as many as 6000 rounds with only the same amount of enlargement that was now found to be produced in 3000 rounds. The great importance however of employing measurement in proving any description of ordnance was evident, in order to have reliable means of determining how many rounds a gun should sustain before it became dangerous and absolutely likely to burst.

The President remarked that one point which had been satisfactorily established by the use of the measuring instrument was that the wear of the gun was mainly confined to the powder chamber, and that very little wear was produced by the friction of the shot in the gun. It had been anticipated by some military and naval men that iron shot would never do at all for an iron gun, but that they would wear the gun out in much less than 1000 rounds.

The measurement showed however that, after firing as many as 3000 rounds with the iron shot, the total wear at a distance of 35 inches from the muzzle amounted to only about 1-500th inch on the diameter, or only 1-1000th inch on each side of the bore, which was a very satisfactory result to arrive at.

Mr. B. FOTHERGILL enquired whether it was a cylindrical or spherical shot which produced so little wear in the bore of the gun.

The PRESIDENT explained that the shot was not cylindrical or spherical, but was hexagonal with the corners rounded, fitting the bore of the gun, as shown in the drawing (Figs. 2 and 3, Plate 31), which exhibited the most perfect form of shot for length of range and accuracy of flight; the length of the shot was about three diameters, and the rifling was about one turn in twenty diameters length. The ordinary shot was of cast iron; and it was rounded off at the front end, and tapered a little at the rear, as shown in the drawing (Fig. 2).

Mr. R. NAPIER enquired whether the wear produced by the shot was greater on the lower or the upper side of the bore.

The PRESIDENT replied that the wear of the gun took place upon the flat sides of the hexagonal bore, and there would not be any difference in the wear of the bore on one side more than on another with the polygonal form of rifling.

[redacted]

the corners; this additional windage at the junction of the flats and corners was ·015 inch on each side or ·03 inch in diameter, making a total windage at the corners of ·05 inch in diameter between the bore and the shot.

The 10 lbs. weight of powder employed with the 70 lbs. shot occupied a length of about three diameters in the bore of the gun, the space occupied by the shot and the powder being the same when the proportion of 7 to 1 in weight was adopted, which had been found by experiment to give the best results. In the longitudinal section of the 7 inch gun shown in the drawing (Fig. 1, Plate 31) the powder filled the space A of about 20 inches length, and the shot B occupied also a length of 20 inches. He considered it desirable to put as much powder into the gun as could be wholly consumed before the shot had passed out at the muzzle, and then it was clear that the greatest possible effect was obtained from both the gun and the powder; and in accordance with this condition he had found that as a general rule three diameters length of powder was the best for a solid shot such as he had employed, having a length of about three times its diameter.

Mr. F. J. Bramwell noticed that in the second and third sets of trials with the 70 pounder gun an air space had been left between the powder and the shot, which he presumed had been done for the purpose of increasing the strain on the gun; and he enquired whether a longer air space than the 12 inches left in the trials would still further increase the strain, or whether there was a limit in the increase of strain resulting from the air space.

In reference to the enlargement of only 1-50th inch in the bore after the first 2886 rounds, he enquired whether this small amount of enlargement might not be merely the permanent set resulting from taking up the slack parts of the gun, and not a sign of injury produced by overstraining; and he asked what was considered the proportion of enlargement that must take place with an ordinary charge, without indicating injury to the gun.

The President replied that the air space left between the end of the powder and the shot in the trials was expressly for the purpose of "punishing" or intentionally overstraining the gun, in order to

try the effect of an extreme strain; but in ordinary practice no air space was left, the shot being always rammed home on the powder. With reference to the amount of the air space, some experiments which he had made with rifle barrels showed that the longer the air space the greater was the strain on the gun; and showed also how very severe a strain was produced on a gun by leaving any length of air space at all. The mode in which the strain acted upon the barrel was also very remarkable, the effect appearing to be concentrated at a particular point, producing a definite annular bulge all round the barrel at that point, instead of the enlargement being distributed uniformly over the length of the air space. In a rifle barrel of ·45 inch diameter with a special charge of 120 grains of powder and a special hexagonal shot weighing 700 grains, an air space of 3 inches length being left between the powder and the shot, the bulge was found at $\frac{1}{4}$ inch in front of the point where the back end of the shot had been before firing; and by then lengthening the air space 1 inch, a second bulge was obtained 1 inch in front of the first bulge. This result appeared very striking, the interval between the two bulges being perfectly parallel and well defined in position.

In reference to the question whether the gun might not receive a certain amount of enlargement at first in the way of permanent set, without sustaining any damage, he did not think that this was the case. It should be mentioned indeed that a certain amount of [redacted]

shot of 150 lbs. weight, no enlargement whatever was found to have been produced, and two shots were then fired with the same result; but on firing three shots, an enlargement of about 1-1500th inch was found to have been occasioned at three places near the breech. This showed that the gun would fire two shots without injury, but with three shots it was so far damaged.

Mr. J. KENNAN enquired whether the three shots were put in close to one another, or whether any air space was left between them.

The PRESIDENT replied that no air space was left between the three shots, and they were flat-ended and all in contact, so that they would have the same effect in the gun as if all one shot.

Mr. H. MAUDSLAY asked whether any difference in friction had been found between cast iron shot and wrought iron shot.

The PRESIDENT said he was not able to state whether there was any difference or not, as wrought iron shot was so seldom used, cast iron being almost exclusively employed for the purpose. The small amount of wear produced in the bore of the gun by the friction of the shot might be explained by the circumstance that there was always a certain amount of fouling in the gun from the previous discharge, so that the shot rode upon a coating of fouling every time the gun was fired. There was found to be a little wear just at the muzzle of the gun, in consequence of the shot not being always put in quite straight in loading the gun.

Mr. W. FAIRBAIRN said he had had the pleasure of visiting the President's works on the previous day, and had seen there a very ingenious vent designed by the President for obviating the objection hitherto met with in guns of the vent becoming worn away after repeated discharges so as to require frequent renewal. It consisted of a piece of platinum in the form of a long plug, screwed into the breech of the gun and having the vent hole drilled through its centre, while the inner end of the plug was enlarged into a conical head; and from the results of experiments such an angle of cone had been obtained that neither the wear from the escape through the vent at the moment of discharge nor the pressure of the discharge produced any effect upon the size of the aperture

in the platinum, in consequence of which a much larger number of rounds could now be fired before the vent piece required renewal.

Mr. R. Napier enquired what was the angle of the cone in the platinum vent piece.

The President replied that the inclination that was found the best for the sides of the cone to the axis was about 30°, as shown at T T in the full size longitudinal section of the platinum vent piece (Fig. 8, Plate 33). With a more obtuse cone it had been found that the aperture of the vent became gradually enlarged by the wear caused by the rush of gas through the vent hole; while with a smaller angle than 30° the vent aperture became gradually contracted in size, owing to the platinum cone being driven in by the pressure of the explosion; but with the particular angle of cone that was adopted this gradual contraction just compensated for the wear of the vent, so as to maintain a constant size of aperture. Previously guns required to be vented by means of a fresh tube at about every 400 rounds; but with the platinum vent as many as 4000 rounds had been fired with one vent piece, the only wear being on the flat surface of the end that was exposed to the inside of the powder chamber.

Mr. W. Fairbairn moved a vote of thanks to the President for his very interesting paper, which was passed.

DESCRIPTION OF AN IMPROVED REVERSING ROLLING MILL.

BY MR. JOHN RAMSBOTTOM, OF CREWE.

The improved Reversing Rolling Mill described in the present paper has been in operation for seven months at the Steel Works of the London and North Western Railway at Crewe, having been designed and laid down by the writer. The special point in the arrangement is that the rolls are driven direct by the engine, without the intervention of a flywheel; and the engine and rolls together are reversed each time that a heat is passed through, the rolling being alternately in opposite directions. The idea of reversing a train of rolls by reversing the engine at each passage of the heat through the rolls was first suggested by Mr. Nasmyth, but has never to the writer's knowledge been carried out before.

A general plan of the rolling mill and engines is shown in Fig. 1, Plate 34, and an enlarged plan of the Engines in Fig. 2, Plate 35; Fig. 3, Plate 36, is a side elevation of the engines, and Fig. 4 a transverse section. They are a pair of direct-acting horizontal engines coupled at right angles, as shown in the plan, Fig. 2; and they are reversed, without shutting off steam, by hydraulic power, by means of the arrangement shown in plan in Fig. 2 and in elevation to a larger scale in Fig. 7, Plate 37. The reversing shaft A is connected by links to a piston working in a small cylinder B of 4 inches diameter and $10\frac{1}{2}$ inches stroke, the water pressure being 300 lbs. per square inch. The admission of the water to the cylinder is regulated by a slide-valve worked by the shaft and hand lever CC. This shaft is prolonged and carried outside the engine house, as shown in the plan Fig. 2, in order to place the attendant in a position where he may be able more

easily to seize the right moment for reversing. The shaft C is made hollow, as shown enlarged in Fig. 6; and through it runs a second shaft with hand lever DD, which regulates the main steam-valve E of the engines by the lever and connecting rod F. By this means the attendant standing outside the engine house at G and in full view of the rolls has complete command over the engines by the two handles C and D. A hand lever is also fixed on the reversing shaft A, as a provision for reversing the engines in the event of any accident occurring to the hydraulic gear or any deficiency in the water supply.

The engines make $3\frac{1}{4}$ revolutions for one revolution of the rolls, and the speed of piston is about 4 times (4·14) that of the circumference of the rolls. The cylinders H H, Fig. 2, are 28 inches diameter with 4 feet stroke. The expansion link K, Fig. 3, shown to a larger scale in Fig. 5, is the straight link devised by Mr. Alexander Allan, and is driven by three eccentrics and rods, two at one end and one at the other, so as to avoid the oblique thrust inevitable with only two eccentric rods.

The connection between the engines and the mill train is made, first by means of an ordinary clutch shown at JJ in Figs. 1 and 2, and secondly by a friction coupling designed by the writer, and shown in position at LL. This friction coupling is shown enlarged in Figs. 11 and 12, Plate 40. The disc M is keyed on the driver shaft N, and a smaller disc O is mounted wobbler-fashion on the [redacted]

an occurrence is very much diminished, and many stoppages and breakages are avoided, whereby loss of capital is prevented.

The engines are of such power that there is no necessity to do more than just start them before the heat enters the rolls. Thus the heavy flywheel usually employed is not required, and consequently the engines are easily reversed; neither is there any expenditure of steam except at the very time of rolling. For the same reason the wear and tear of machinery and the necessary lubrication are reduced to a minimum in this mode of driving the rolls. Instead of the heavy flywheel employed in the ordinary arrangement of rolling mills as a reservoir of power, in which the power of the engine is previously accumulated ready to be concentrated upon the work at the time of rolling, the boiler is made to serve as the reservoir of power in the new rolling mill; and it has this great advantage, that whereas the flywheel contains only a limited store of power, which continues diminishing during the time of application, the boiler supply is practically unlimited, so that the rolling power continues constant throughout the time of operation.

In the rolling of puddled slabs for the frame plates of locomotive engines, which are reduced $3\frac{1}{2}$ inches in thickness at one heat in the rolls, about twenty-one reversals of the rolls are required. These are effected with great ease and almost instantaneously by the arrangement above described, the shock being transmitted to the elastic cushion of steam in the cylinders of the engines. This handiness allows of either iron or steel plates being passed through both the roughing-down rolls and the finishing rolls at one heat; and the work is thus done with a minimum expenditure of heat and waste of metal. It has been found on trial not at all difficult to reverse the engines together with the whole train of rolls as many as 73 times in one minute.

There are two pairs of Rolls, one for roughing down and the other for finishing. The roughing-down pair are 24 inches diameter by 6 feet length; they are shown in elevation and plan in Figs. 8 and 9, Plates 38 and 39, and Fig. 10, Plate 40, is an end elevation;

Figs. 13 and 14, Plate 41, are transverse sections through the housing and through the rolls.

In these rolls a new description of tightening-down gear has been designed, in order to obtain greater facility and accuracy in tightening down the rolls, and to ensure the top roll being at all times perfectly parallel to the bottom roll. This gear is shown in Figs. 8, 9, and 14. It consists of a vertical wrought-iron shaft Q, carried by a cast-iron bed-plate and supported at the upper end by the wrought-iron standard S, between the housings, and in the centre of the length of the rolls. On the top of the shaft is keyed a spur wheel T, which drives the two spur wheels UU on the vertical holding-down screws of the top roll R. These screws work in steel nuts let into the housings, as shown in Fig. 13, and the top bearing of the centre shaft Q is also a corresponding screw working in a brass nut, so that the centre spur wheel T rises and descends simultaneously with the two outer spur wheels UU when the gear is in motion. A vertical hydraulic ram V, Figs. 8 and 10, is placed in a convenient position near the rolls; and a chain, shown by the thick dotted line, is fastened at one end to the barrel of the ram, carried thence over the pulley on the ram head V, down again to the fixed pulley below, and thence round a guide pulley X on the nearer roll housing to the spiral chain-barrel upon the lower end of the vertical centre shaft Q. The chain makes a few coils round the barrel, and the end is fastened to the barrel near the top.

repeated after each passage of the slab through the rolls. When the rolling is completed, the water is released from the ram, and the ram falls, while the counterbalance weight W on the second chain winds up the tightening-down screws to their original position; and the usual counterbalance apparatus Y, Figs. 8 and 13, applied to the top roll R, causes it to rise with the upper chocks.

The head V of the hydraulic ram, Figs. 8 and 10, carries an index finger, which by means of graduations on the guides enables the attendant to give with accuracy the requisite amount of lowering of the top roll at each reversal, and thereby to reduce each slab with certainty to exactly the same thickness. As an additional precaution in rolling a set of slabs all to the same thickness, a chalk mark is made on one of the spur wheels U, after the final rolling of the first slab; and at the final rolling of each successive slab of the same set a stop is placed in the teeth of the spur wheel at this mark, stopping the screwing down always at the same point, and thus preventing the possibility of any mistake in the finished thickness of any slabs of that set. The total vertical motion given to the roll by the hydraulic ram is 3½ inches, while the stroke of the ram is 6 feet 2½ inches; consequently the movement of the ram is 21 times that of the roll, and the indication by which the tightening of the rolls is measured being thus magnified 21 times gives great accuracy in the adjustment.

By this system of gearing the two tightening-down screws together by means of the intermediate spur wheel, the top roll is made to move always truly parallel to the lower roll, and there is no possibility of one end of the roll descending more than the other. Thus the two surfaces of the slabs rolled are made perfectly parallel to each other, with a uniform thickness throughout the entire width of the slab.

In the finishing rolls the same tightening-down gear is employed. These rolls are of cast iron chilled on the circumference, 24 inches diameter by 7 feet length; and they differ in no important respect from the roughing-down rolls. As the finishing rolls require only a small vertical motion, no counterbalancing gear is applied to the top roll as in the previous pair, the bottom chocks of the top roll

being supported by the ordinary transverse spring beams passed through the housings.

In order to facilitate the introduction of large slabs into the roughing-down rolls, a set of bent levers ZZ, Figs. 8 and 14, shown to a larger scale in Fig. 15, Plate 42, are attached to a horizontal shaft B running along the ground parallel to the rolls; and by means of a hand lever H on the shaft all these levers are simultaneously brought up under the slab, and by a slight movement the slab is then lifted into the rolls. Each of the levers is attached to the shaft B by an arm and pin joint, so that it can yield to any inequality on the surface of the slab; and it is brought up again by the overhanging counterbalance ball A.

From the fact that the train of rolls driven in this manner is only in motion while the heat is being passed through, it is not found necessary to use a stream of water for lubricating the roll bearings in the ordinary manner; but all the journals are truly fitted in the bearings, and are lubricated with oil and tallow.

Mr. R. Napier asked whether any break-downs or accidents had occurred since the mill was first started.

Mr. Ramsbottom replied that they had had no accidents of any sort during the seven months that the mill had now been at work.

Mr. W. Fairbairn enquired whether the rolling mill was employed for rolling down ingots of steel; and whether the same plan would not be applicable for rolling armour plates.

Mr. Ramsbottom said he had not used the mill for rolling down steel ingots, but it was employed chiefly in rolling the frame plates for locomotives. For armour plates he thought the reversing mill would be very suitable, and the only question was one of gearing and power for rolling any size of armour plate that might be required. He had had no difficulty at present in rolling anything that had been put into the mill. On one occasion he had rolled a circular steel saw-plate, 7 feet diameter, which was of course rolled in a single piece. It had been objected to the plan of keeping the rolls parallel, by gearing the tightening-down screws together, that the plates sometimes wanted humouring, by tightening the top roll down more at one side than the other, which could not be done when the screws were geared together ; but in practice the utmost extent of the humouring required was so slight that he had found it was only necessary to pass the plate through nearer to one side or the other, as the rolls themselves were not turned truly cylindrical, but slightly larger in diameter in the centre to compensate for the springing under the strain in rolling.

Mr. R. Napier remarked that the levers employed for entering a slab into the rolls looked very light, and he enquired whether they were found strong enough for the purpose.

Mr. Ramsbottom replied that the levers were made of pieces of ordinary spring steel $\frac{1}{2}$ inch thick and $3\frac{1}{2}$ inches broad, and there were four of them on each side of the rolls, and though light in appearance they completely answered the purpose of lifting the slabs into the rolls ; and with this arrangement one man at the hand lever could do more than four or five men by the old plan of running a truck at the slab to force it into the rolls.

Mr. B. Fothergill remarked that in ordinary ironworks where there were a number of furnaces in connection with the same set of rolls, the heats to be rolled would be of different thicknesses, so that it would be necessary to lower the rolls immediately from a bar or slab of say 3 inches thickness to a plate only 1 inch or $\frac{3}{4}$ inch thick; and he enquired how quickly the tightening-down gear could be altered in the new rolling mill, for changing the gauge of the rolls to suit such requirements, and whether this was done as quickly as in the usual mode by hand.

Mr. Ramsbottom replied that the top roll in the new rolling mill had a motion of $3\frac{1}{2}$ inches, and from the full width of opening it could be brought down in a few moments through the whole range of $3\frac{1}{2}$ inches by means of the hydraulic tightening-down gear, nor had any inconvenience or delay been experienced from this cause. The alteration was effected quite as quickly as with the ordinary tightening-down screws worked by hand and independent of each other; and the adjustment was made with much greater accuracy by the hydraulic apparatus, the $3\frac{1}{2}$ inches range of motion of the top roll being magnified 21 times on the scale of the hydraulic ram, which was constructed according to the arrangement of Sir Wm. Armstrong's hydraulic cranes. The range of the top roll could be further increased if desired, by altering the proportion of the gearing.

Mr. S. Lloyd observed that the old plan of reversing the rolls [redacted]

tool half round for cutting during the return stroke, when the length of travel was anything considerable; but with a very short travel this was of less consequence, and the return motion might be made without cutting.

Mr. Ramsbottom replied that one of the best illustrations of the facility of reversing the rolls was the mode adopted for rolling down the crop ends of plates into small sheets 1-16th inch thick, to be used as covers for the moulds in casting the Bessemer steel ingots. The men were left to themselves as to the mode of working, and they preferred to reverse the rolls for these small pieces of metal instead of passing the work over the top roll, as they found they could get on much quicker by reversing.

Mr. F. J. Bramwell remarked that as the engine drove the rolls direct in the new mill, without the use of a heavy flywheel, the engine itself must be of greater power, and he asked for some information respecting the comparative cost; he thought it probable the saving effected by avoiding the expense of the heavy flywheel would compensate for the cost of the larger engine.

Mr. Ramsbottom considered the engine working direct on the rolls to be certainly more economical in first cost than the ordinary plan of using a flywheel. In the present instance the engine employed was larger than was actually needed, having been put down originally for driving the tyre mill, and it had afterwards been applied to the rolling mill for the purpose of testing the plan of reversing, because it was not possible to reverse with a flywheel. In putting down a new rolling mill for the same class of work, it would not be necessary to have so large an engine as that shown in the drawings. It was of course requisite to have a second cylinder working at right angles, when the flywheel was dispensed with; but even with a flywheel two cylinders were not unfrequently employed.

Mr. R. Napier enquired whether the work was done with less expenditure of steam by dispensing with the flywheel.

Mr. Ramsbottom had no doubt that the expenditure of steam was not greater than with a flywheel, and there was certainly less wear and tear, and a great saving in time. The flywheel involved the

defect in principle of going twice over the ground, the speed being first increased by gearing from the engine to the flywheel, and then reduced again by gearing from the flywheel to the rolls; and that process necessarily occasioned a waste of power by friction, which was saved by the present plan of dispensing with the flywheel.

Mr. E. T. Bellhouse thought the new reversing rolling mill presented a very important practical embodiment of the great principle advocated by Mr. Nasmyth, of applying steam power direct to the work required to be done. In former years mechanical engineers had laboured under great disadvantages, owing to the want of machinery sufficiently accurate and fine for accomplishing properly the desired work. Hence it arose that, in forging, the principle of the common hammer had been made use of, and the hammer itself had been made of very great weight and driven by a powerful engine with very heavy flywheel, in order to perform the work by the aid of momentum. Subsequently these cumbrous engines and massive flywheels were superseded by Mr. Nasmyth by the direct application of the steam to the work, in the steam hammer of his invention; by which the power could be applied with the utmost nicety, exactly in proportion to the work to be done. The same important principle had since then been followed up in many other instances, and was now carried out in the new rolling mill that had been described, in which the stopping and reversing [redacted]

comparatively small size, each working direct upon its own machines, might perhaps be advantageously carried out in the case of cotton mills and similar manufactures, instead of the present plan of driving the whole of the machinery in the works by a single engine of very large size; the principle had been already adopted in print works and warehouses, as well as in many engineering works.

Mr. J. Fernie said he had recently seen the reversing rolling mill in operation at Crewe, and could fully bear out all that had been stated in regard to the very efficient way in which it worked; but in existing ironworks it generally happened that an engine had been put down for more purposes than one, and then this reversing arrangement would not be applicable. At the works with which he was connected the tyre mill and plate mill were both driven by the same engine, so that reversing by the plan adopted at Crewe was not practicable. He should like to enquire whether in making common iron the plates would stand this mode of rolling, and whether the reversing would not injure the fibre.

Mr. W. M. Sparrow thought there must be a severe concussion between the teeth of the two spur wheels gearing the engine to the mill, whenever the rolls were reversed while running at any considerable speed; and he enquired what had been the experience in respect to the wear of the wheels.

Mr. Ramsbottom replied that he had not experienced any drawback from the wear of the gearing, as the parts which moved quickly were all so light, and there was no large mass in motion such as a heavy flywheel, and only the action of the elastic steam to check and reverse the motion. The power being brought to bear upon the work just as wanted, and direct from the engine, there was no accumulated force to be checked in reversing, and no more force was called into play than was actually required for accomplishing the rolling. The reversing was thus effected with no more trouble or wear than in the ordinary reversing of a locomotive engine.

With regard to rolling the plates in both directions in the reversing rolling mill, he had heard it objected by steel makers that steel would be deteriorated in quality by being rolled both ways; but having himself tested the steel that had been rolled both ways,

he had found no difference in quality between that and the steel rolled only one way.

Mr. W. Fairbairn considered it was immaterial in the manufacture of iron or steel whether the metal was rolled first in one direction and then in the other or rolled continuously in one direction only. The only effect of the rolling, as regarded the quality of the material, was that, supposing it to be a crystallised substance in the first instance, the crystals were elongated and formed into fibres by rolling. He had had an opportunity of seeing the new rolling mill at work a few days previously, and had certainly never seen any machinery better adapted for the purpose in view. With a flywheel of 40 or 50 tons weight, reversing would have been impracticable, because it could not have been stopped in time without destroying the machinery; but by getting rid of all that enormous mass in motion the rolls could now be reversed with the greatest facility. The reversing mill was an important move in the right direction, establishing a new method in the manufacture of both iron and steel, in consequence of which he had no doubt that they would be manufactured at a much lower cost than heretofore.

Mr. Ramsbottom observed that one source of saving would be that the work was got over more rapidly in the reversing rolling mill. With regard to the principle introduced by Mr. Nasmyth of applying steam direct to the work to be performed, as in the present instance, it might be remarked that this principle was gradually [redacted]

the new rolling mill, there would be considerable waste in shearing the plate square; but if the tightening-down screws were under independent control, they could be so managed as to bring up the wasted portion in rolling, so that the plate would not be wasted in shearing afterwards. On these accounts he thought it was preferable to have the tightening-down screws independent of each other, instead of gearing them together.

Mr. RAMSBOTTOM said no difficulty such as was referred to had been experienced with the tightening-down screws geared together. In rolling plates it was customary to pass the bloom through sideways in the first instance, which made it uniform in thickness throughout its entire breadth, so that any waste in the furnace would be corrected by this process; and it was then turned round and finished for length. The rolls not being made quite parallel, but rather larger in diameter at the middle, any minor errors were met by going a little nearer to one end or the other of the rolls; and if more serious errors were ever occasioned by irregular heating in the furnace, he thought there should be a change in the management of the furnace, rather than working the tightening-down screws separately.

Mr. W. YULE said he had had many years' experience in working rolls in which the tightening-down screws were geared together, and he had never met with any difficulty arising from that plan.

Mr. H. MAUDSLAY observed that in rolling angle iron or bar iron in an ordinary rolling mill, where the rolls ran constantly in the same direction, it was the practice to turn the iron over in passing it back over the top roll, so that the scale might be well knocked off before entering it again between the rolls. But in passing a heat backwards and forwards alternately through the reversing rolls, the scale would remain where it was on the iron; and he enquired whether the old plan would not have an advantage in this respect, by allowing of the iron being turned over and cleared from scale between each passage through the rolls.

Mr. RAMSBOTTOM replied that they had not as yet rolled any angle iron in the reversing rolling mill; but in rolling plates no difference was found between one side of a plate and the other,

as regarded scale. The large plates were not turned over during rolling, but the scale fell away freely from the lower side, and was always brushed off from the upper side with a broom between each passage through the rolls.

The PRESIDENT thought the improvements described in the paper that had been read were well worthy of being generally adopted in rolling mills; and he moved a vote of thanks to Mr. Ramsbottom for his paper, which was passed.

The Meeting was then adjourned to the following day. In the afternoon the Members were conveyed by special free train, by the kindness of the London and North Western Railway Company, to Crewe, to visit the Steel Works of the London and North Western Railway, where they were shown by Mr. Ramsbottom the manufacture of steel by the Bessemer process, and the manufacture of steel tyres; and also the operation of rolling plates in the reversing rolling mill described at the meeting.

The Adjourned Meeting of the Members was held in the Lecture Theatre, Mechanics' Institution, David Street, Manchester, on Wednesday, 1st August, 1866; JOSEPH WHITWORTH, Esq., President, in the Chair.

The following paper, by Mr. Edward B. Marten, of Stourbridge, Engineer of the Midland Steam Boiler Association, was read:—

ON STEAM BOILER EXPLOSIONS AND THEIR RECORDS, AND ON INSPECTION AS A MEANS OF PREVENTION.

By Mr. EDWARD B. MARTEN, of Stourbridge.

The subject of Steam Boiler Explosions, which was brought before this Institution in June 1848 in a paper by the late Mr. William Smith of Dudley in reference to an explosion near that place, and again in 1859 in a paper by Mr. Longridge on the economy and durability of stationary boilers, is one of great importance and is now attracting increased attention. The first public notice of the subject was by a parliamentary committee in 1817, which was appointed in consequence of a very fatal boiler explosion in London in 1815; evidence was then collected as to steamboats, and many boiler explosions were referred to. That committee recommended among other things that boilers should be made of wrought iron, instead of cast iron or copper, which had been the materials mainly used previously; that they should be inspected and tested; and that there should be two safety valves, each loaded to one third of the test pressure, under penalties for any excess. A great part of

When the writer's attention was first directed to this subject, he met with great difficulty in obtaining correct records of boiler explosions, from which to arrive at the results of past experience; and wishing to base his own opinion on facts, rather than on the inferences of others however reliable, he followed the example of the Franklin Institute in their elaborate investigation of the subject, and collected all the records he could find; and by way of facilitating reference, arranged an index, a manuscript copy of which is presented with the present paper to the Library of this Institution. All must be agreed as to the importance of reliable information on such accidents as boiler explosions; and the writer would suggest that this Institution may materially aid in obtaining the desired records and placing them within easy access, by becoming the depository of reports on explosions, and by inducing those who have the opportunity to forward copies of reports, that these may be arranged so as to be easily found and consulted. It is very desirable that these reports should as far as possible be illustrated by sketches, as aids to the description; and also by slight models like those now shown to the meeting, by which the whole matter may be seen at a glance. So few persons comparatively have the opportunity of examining boilers after explosion, that the most erroneous ideas have prevailed, and theories have been advanced which would soon be dissipated by practical experience or by reading accurate reports. It would also very much aid in the understanding of published matter on the subject, if full descriptions of each case alluded to in illustration could be obtained. These records are as useful to the engineer as the "precedents" or "cases" to the lawyer or the surgeon. After any serious explosion the newspapers of the neighbourhood in which it has occurred contain voluminous articles describing the disastrous result and the damage done, which, although useful as far as they go, do not in the least assist in arriving at the cause of explosion. The really important particulars, such as the description and construction of the boiler, its dimensions, and the pressure at which it worked, are in most cases omitted altogether.

The record of explosions presented to the Institution contains a list of the boiler explosions in each year of the present century, as far as known to the writer, with the names of the places, and the description and sizes of the boilers, and the supposed cause of explosion, together with references to the books or papers from which further information may be obtained. Of course many of the explosions have to be put down as uncertain in some of the particulars; but every year improves the record, as fresh information is obtained, and with the assistance of the members of this Institution it might be made far more perfect and extensive.

The total number of explosions here recorded is 1046, and they caused the death of 4076 persons and the injury of 2903. The causes assigned for the several explosions are very numerous, and are no doubt incorrect in many cases; but they may be generally stated as follows:—

397 are too uncertain to place under any heading; but of the rest

145 were from the boilers being worn out, or from corrosion, or from deteriorated plates or rivets.

137 from over pressure, from safety valves being wedged or overweighted, in some cases intentionally, or from other acts of carelessness.

125 from faulty construction of boiler or fittings, want of stays, or

[redacted]

The exploded boilers were of the following descriptions:—

232 are not sufficiently described to place under any head; but of the rest

320 were Marine boilers of various forms.

141 were Cornish, Lancashire, or other boilers internally fired.

120 were Locomotive, or other multitubular boilers.

116 were plain Cylindrical boilers, externally fired.

64 were Balloon or haystack, wagon, Butterley, British-tube, elephant, or Trevithick boilers.

29 were Portable, agricultural, upright, or crane boilers.

14 were Heating apparatus or kitchen boilers.

10 were Upright boilers attached to puddling or mill furnaces at ironworks.

1046 total number of explosions.

The theories as to the causes of explosion have been numerous. In the early days of the steam engine, when the steam was used only as a condensing medium and the pressure in the boiler was frequently allowed to get below atmospheric pressure, many boilers were destroyed by the excess of the external atmospheric pressure becoming too great, causing them to be collapsed or crumpled up; and this led to the use of the atmospheric valve still found on old boilers. Even so lately as last year a boiler in the neighbourhood of Bury, Lancashire, has suffered in this way by collapse from external pressure; its appearance after the accident is shown in Fig. 4, Plate 43, which is copied from a photograph. The early explosions were so palpably due to the weakness of the boilers, which compared with those of the present day were most ill constructed, that no one thought of any other cause than the insufficient strength of the vessel to bear the expansive force of the steam contained in it. When the advantages of high-pressure steam became recognised, and the boilers were improved so as to bear the increased strain, the tremendous havoc caused by an explosion led many to think that something more must be required than the expansive force of the steam to produce such an effect; and they appear to have attributed to steam under certain conditions a

detonating force, or a sudden access of expansive power that overcame all resistance. To support this somewhat natural supposition, it was asserted that the steam became partially decomposed into its constituent gases, forming an explosive mixture within the boiler. That this belief is still sometimes entertained is seen from the verdict of a jury even in the present year, in the case of the explosion of a plain cylindrical boiler at Leicester, shown in Fig. 18, Plate 46, the real cause of which appears to have been that the shell of the boiler was weakened by the manhole. It seems hardly necessary to point out the fallacy of imagining decomposition and recomposition of the steam to take place in succession in the same vessel without the introduction of any new element for causing a change of chemical combination; but it is necessary to refer to this supposition, as the idea is shown to be not yet extinct.

Again it has been asserted that the steam when remaining quite still in the boiler becomes heated much beyond the temperature due to the pressure; and that therefore when it is stirred or mixed or brought more in contact with the water by the opening of a valve or other cause, the water evaporates so rapidly as to produce an excessive pressure by accumulation of steam. In support of this view the frequency of explosions upon the starting of the engine after a short stand is adduced; but it is very doubtful whether by this means a sufficient extra pressure could be produced to cause an explosion.

The most important points to find out in connection with any explosion are the condition of the boiler and all belonging to it immediately before the explosion, together with the locality of the first rent, the direction of the line of rupture, and the nature of the fracture; as everything occurring after the instant of the first rent is an effect and not a cause of explosion. As soon as the first rent has taken place, the balance of strain in the fabric is disturbed, and therefore the internal pressure has greatly increased power in continuing the rupture; and also the pressure being then removed from the surface of the water, which is already heated to the temperature of the steam, the whole body of the water gives out its heat in the form of steam at a considerable pressure, and thus supplies the volume of steam for carrying on the work of destruction. When thus quickly generated, the steam perhaps carries part of the water with it in the same way that it does in ordinary priming; and it has been thought by some that the impact of the water is thus added to that of the steam, to aid in the shock given to all surrounding obstacles.

It is seldom that one out of a bed of boilers explodes without more or less injury to the others on either side of it; but sometimes two boilers in one bed, or three, or even five, have exploded simultaneously.

The causes of boiler explosions may be considered under the two general heads of—

Firstly, faults in the fabric of the boiler itself as originally constructed, such as bad shape, want of stays, bad material, defective workmanship, or injudicious setting:—and

Secondly, mischief arising during working, either from wear and tear, or from overheating through shortness of water or accumulation of scurf; or from corrosion, in its several forms of general thinning, pitting, furrowing, or channelling of the plates; or from flaws or fractures in the material, or injury by the effect of repeated strain; or from undue pressure through want of adequate arrangements for escape of surplus steam.

There is no doubt that many of the early explosions were from faults of construction. The stronger materials now used were then found so difficult to manipulate that others easier to work were chosen, and often the shape of the boiler was only selected as the one easiest to make. The early boilers were made of copper or cast iron, with leaden or even wooden tops, and of the weakest possible shape. Such was the boiler used by Savery, shown in Fig. 40, Plate 51, and the Tun boiler and Flange boiler, Figs. 41 and 42. The very fatal explosion in London in 1815, referred to by the parliamentary commission previously named, was of a cast-iron boiler, which failed because one side was too thin to bear the pressure, as the casting was of irregular thickness. The steam being at that time used only at or below atmospheric pressure as a means of obtaining a vacuum by condensation for working by the external pressure of the atmosphere, so little was pressure of the steam thought of that boilers were proposed and it is believed were actually constructed with hooped wooden shells, like barrels, and internal fireplaces and flues of copper; and even a stone chamber was named as being a suitable shell for a boiler, with internal fireplace and copper flue passing three times the length of the inside and out at the top, like an ordinary stove and piping. These boilers must have been something like the sketches given in Figs. 44 and 45, and were intended to be exposed only to the [redacted]

proportionately thinner; as in Woolf's boiler, so much spoken of in the evidence before the parliamentary committee of 1817. This boiler, shown in Fig. 47, consisted of nine cast-iron pipes, about 1 foot diameter and 9 feet long, set in brickwork so that the flame played all round them. These small tubes were connected with another of larger size placed transversely above them, forming a steam receiver, and this again with a still larger one, which formed a steam chamber. No details of any explosions of the three last mentioned boilers have been obtained; but it is known that the cast iron was found a most treacherous material, especially when exposed to the action of the fire; and that the effect of explosion was very disastrous, because the boiler burst at once into many pieces, each of which was driven out with great velocity, and the danger was not mitigated by the circumstance of large masses holding together, as is found to be the case with wrought-iron boilers when exploded.

When wrought-iron boilers came into use the shapes were most varied, and the dimensions much larger than before. One of the earliest was the Wagon boiler, shown in Fig. 48, Plate 52, with round top and plain flat sides, which could only be made to bear even the smallest pressure by being strengthened with numerous stays. In most cases of explosion of this class of boiler the bottom was torn off, owing to the angle iron round it being weakened by the alternate bending backwards and forwards under each variation of pressure, as all the sides and the bottom must be constantly springing when at work. Such was the explosion at Chester in 1822, and many others. This shape was soon improved in its steam generating powers by making the sides concave instead of flat, as shown in Fig. 49, so that the heating surface was greater and also in a better position to receive the heat from the flame in the flues. This shape was further elaborated by rounding the ends, as in Fig. 50, and in some cases making the bottom convex to correspond with the top, as in Fig. 51. All these forms however still required numerous stays to retain them in shape, the safety of the boiler being dependent upon the stays; and numerous explosions show the

weakness of these boilers. They generally gave way at the bottom, as in an explosion that occurred at Manchester in 1842, where the boiler had been weakened by frequent patching; they also sometimes exploded through the failure of the stays.

A very early improvement in the right direction consisted in making the shell circular; and some few large boilers still exist that were made completely spherical, as shown in Fig. 52, so that the whole of the iron was exposed to tension only, and required no assistance from stays, and the boiler had no tendency to alter its shape under varying pressure. This shape however had the great disadvantage of possessing the least amount of heating surface for its size or cubic contents; and also it was very liable to injury from sediment on the bottom, which accumulated on the most central spot. The spherical form was therefore soon modified into the shape shown in Fig. 53, by making the bottom more shallow, although still convex; and afterwards by putting flat or concave sides and a flat or concave bottom, with the angle constructed either of bent plates or angle iron, as in Figs. 54 and 55, which represent the forms known so well in the Staffordshire district as the common Balloon or Haystack boiler. Many of these have been made of very great size, measuring as much as 20 feet diameter, and containing so much water and steam as to be most formidable magazines for explosion. Perhaps no form of boiler has exploded more than this, partly because of the great [redacted]

Notwithstanding the dependence of these boilers upon stays for their strength, many have been made as large as 12 and 15 feet diameter without stays; and explosion sooner or later has been the consequence. Such was an explosion that took place at Smethwick in 1862, which is shown in Fig. 5, Plate 43. As the force of the explosion was only slight, the effect of the bottom giving way, and the consequent rolling over caused by the reaction of the issuing steam and water, is clearly seen. Another example that occurred at Wednesbury in 1862 is shown in Fig. 1, where the explosion was rather more violent, the bottom of the boiler being torn off all round and left upon the firegrate, and rent nearly into two pieces; while the top and sides were thrown some height in one mass, and were only put out of shape by the fall. The weakness of this boiler had been further increased by making the bottom angle of angle iron, as shown enlarged in Fig. 2, with a ring of flat plate A interposed between the angle-iron ring and the concave bottom of the boiler; so that all the effect of the springing of the bottom, as shown by the dotted lines, was thrown upon the angle iron, which was accordingly found cut off all round. Had the concave bottom been made to rise direct from the angle iron, as in Fig. 3, the springing could not have been so great, and the angle iron would only have had to stand the shearing strain of retaining in its place the rigid bottom; but as about one foot all round the bottom was flat, and the concavity was only in the central part, the angle-iron ring had to bear an up and down strain, as shown by the dotted lines in Fig. 2, and the bending action was more severe than it would have been if the bottom had even been made quite flat all over.

A further form of the Balloon boiler is shown in Fig. 56, Plate 53, where the heating surface of the bottom is increased by an internal central dome-shaped fireplace, with an arched and curved flue conducting the flame through one revolution within the boiler before passing again round the outside. This construction however must necessarily have diminished the strength of the boiler greatly. In the drawing the top of the boiler, as indicated by the dotted lines, is removed to show the interior.

The desire to add to the strength of boilers by lessening the diameter of the shell led to the construction of the Plain Cylindrical boilers. They were made first with flat ends of cast iron, which frequently cracked and gave way when exposed to the fire, as described in many of the early American explosions. The flat ends when made of wrought iron, as shown in Fig. 57, Plate 53, are exposed to the same strain as the bottom of the balloon and wagon boilers, and are constantly springing with variation of pressure like drum heads, causing injury to the angle-iron joint. They also require long stays through them to hold in the ends, and these are subject to so much vibration that they seldom continue sound for long together, especially when joined with forked ends and cotters.

As the flat ends of such boilers are always being sprung by each alternation of pressure into a more or less spherical shape, as shown by the elastic model exhibited, this consideration no doubt led to the ends being made hemispherical, as shown in Fig. 58; and plain cylindrical boilers with these hemispherical ends are now so commonly used that they far outnumber any other form of boiler. Their shape renders them very strong, as the whole of the iron is in simple tension, and internal pressure has no tendency to alter the shape, as is shown by the elastic model exhibited. There is one circumstance very much in favour of the plain cylindrical boilers, and that is that they can be so easily cleaned and repaired, as a man can

therefore be better to have a succession of short boilers, rather than only a single one, where great length is required.

One boiler has been seen by the writer where extreme length was avoided by curling the boiler round until the ends met, forming a Ring or Annular boiler. This boiler is shown in Fig. 59, Plate 53, and is 5 feet diameter with 25 feet external diameter of the ring, or a mean length of about 63 feet; it has been found to work well for some years, although exposed to the heat of six puddling furnaces.

Explosions of plain cylindrical boilers have been very frequent indeed, although they have not caused a proportionate number of deaths, because they work usually in isolated positions at colliery and mine engines. The sketch shown in Fig. 6, Plate 44, represents an explosion that occurred at Darlaston in 1863, and illustrates the way in which these boilers usually explode. They generally open first at a longitudinal seam over the fire, which has become deteriorated by accumulations of scurf preventing proper contact of the water, so that the plates become overheated, their quality injured, their edges cracked or burnt, and the rivets drawn or loosened. The rent generally continues in the longitudinal direction to the sound seam beyond the bridge at the one end, and at the other end to the seam joining the front end to the shell; and then runs up each of the transverse seams, allowing the rent part of the shell to open out flat on both sides, and liberating both ends of the boiler, which fly off in opposite directions. Of course it is seldom that an explosion is quite so simple as this, as the direction of the flight of the various pieces is so much influenced by the last part that held in contact with the main body of the boiler. The want of due observation of this point has often led to erroneous conclusions.

In the explosion shown in Fig. 7, Plate 44, and in the model exhibited, which occurred at Westbromwich in 1864, the lower part of the side of an upright boiler was blown out; and the liberated part was also divided into two pieces, each of which fell some distance behind the boiler, in an opposite direction to the side from which they came. The explanation of this became obvious on examination, as the cause of the rupture had been the corrosion of

the bottom, and the rent had run up the seams until it met the angle iron of the side tubes, round which it ran to the first seam above. This seam acted as a hinge on which the ruptured pieces turned, and they swung round so violently that they were wrenched off, but not before they had pulled the boiler over and received the diverting force which gave them their direction, for they flew off at a tangent to the circle in which they had swung round on the sound upper seam as upon a hinge.

In order to avoid having a large diameter for plain cylindrical boilers, especially where exposed to the fire, boilers have been used that have supplied the required steam power by a combination of several cylinders of small diameter. One of these, known as the Elephant boiler, has been so much used in France that it is sometimes called the French boiler; it is shown in Fig. 61, Plate 53, and consists of two cylinders of small diameter connected by upright conical tubes to a large cylinder above. Another form called the Retort boiler, shown in Fig. 60, has been described at a previous meeting of this Institution (see Proceedings Inst. M. E. 1855 page 191). The disadvantages of these two combinations of plain cylinders are that they are not easy to clean or examine internally, and also there is not free exit for the steam, which has to find its way along small channels, and carries the water away with it, causing priming, and also retarding the generation of steam and endangering the boiler plates. With a view to strengthen the plain

boiler: in Fig. 64 two tubes pass from the sides to the front: in Fig. 66 the tube passes from the back, but returns over the fire and passes again to the back: and in Fig. 65 a tube from the back passes out through a cross tube in each side. The boilers in all these cases are fired externally. This addition of tubes has tended very much to increase the size of these boilers in order to make room for the tubes. These boilers are now found of 9, 10, and even 11 feet diameter; and this large shell being fired externally is exposed to the same dangers as those described in the plain cylindrical boiler, while it is not so easy to keep clean on account of the obstruction offered by the internal flues. When the flame has passed under the whole length of the bottom of these large boilers before going through any tube, it is doubtful whether the heating surface of the tube helps much in the generation of steam; but the tube is of use in reducing the quantity of water in the boiler, as it occupies a considerable space.

Explosions of these boilers have sometimes taken place by collapse of the tubes, but much more generally by the failure of the shell over the fire, as shown in the sketch Fig. 8, Plate 44, representing an explosion that occurred at Wolverhampton in 1865, in which the first rent took place in a seam over the fire where frequent repair had led to a considerable length of longitudinal seam being in one continuous line. The four plates over the fire parted and opened out until they had ripped two seams completely round the boiler; and the plates were thrown in one flat piece, as shown, upon a bank behind. The main body of the boiler with the tubes was turned over, and the front end blown away.

A modification or amalgamation of several of the forms of boilers already mentioned led to the construction known as the Butterley boiler, shown in Fig. 72, Plate 55, with a wagon-shaped end over the fire, continued in a single tube within a plain cylindrical shell beyond. This boiler has been found to generate steam very rapidly; but the extreme weakness of the construction over the fire and along the tube, especially at the part where the front end of the tube widens out in a bell mouth to meet the wagon-topped fireplace, has led to

so many explosions that few boilers are now made of this form. A very early explosion that occurred at Edinburgh in 1821 was of a boiler somewhat of this shape, only that the wagon-topped fireplace was much longer. Other explosions of this form of boiler occurred at Ashton-under-Lyne in 1845, at Wolverhampton in 1854, and at Tipton in 1856.

The desire to economise fuel led to placing the fire inside the boiler, in a tube running from end to end, as shown in Fig. 67, Plate 54; and the great number of boilers of this form used in Cornwall gave it the name of the Cornish boiler. The exceedingly good duty performed by these boilers led many to believe them the most perfect for economy and durability; but the great number of explosions, or more properly of collapsed flues, that have happened, have altered this opinion, and led to the double-flue boiler shown in Fig. 68, in which not only is the heating surface increased but the strength also, by having two tubes of smaller diameter in the same shell. There are a great many varieties of the two-tube boiler, which have been made for the purpose of obtaining various particular results. In some cases the two tubes have been made to unite into a single tube immediately behind the fires, forming what is known as the Breeches-tube boiler, as shown in Fig. 69; and in other instances the outside shell of the boiler has been made oval, as [redacted]

are still made and used having even large tubes without the strengthening rings; and in some districts such boilers are used in great numbers and at far higher pressures than can be considered judicious. In more than one bed of boilers one boiler after another has exploded by the collapse of the tube from the want of strengthening rings, and yet these have still been believed unnecessary; and the cases of isolated boilers of this construction where the large tubes have collapsed are extremely numerous, yet any other reason than the weakness of the tube has been considered more probable as the cause of explosion. A sketch of a boiler with collapsed flue is given in Fig. 11, Plate 45, which exploded at Burton-on-Trent in 1865; and it is selected from many others because it was a new boiler, well made and mounted, and was a good example of the weakness of a large tube to resist high external pressure when made of great length without the support of strengthening rings.

There are a great many advantages in the tubular boiler internally fired. The shell which is exposed to the greatest tension is not also exposed to the first action of the fire. The fire is in the midst of the water, so that the greatest effect is obtained from it; and the heating surface immediately over the fire, from which most steam is generated, has not so great a depth of water above it for the steam to pass through as in the externally fired boilers heated from the bottom. The tubes also act as stays to the ends; and the mud in the water falls off the tubes, where it would do mischief, and settles on the bottom, where it is comparatively harmless.

These tubular boilers are however subject to disadvantages peculiarly their own. It is not so easy to move about within them for cleaning and examination as in the plain cylindrical boiler, as the tubes fill up the space so much. The difference of expansion between the highly heated tube and the comparatively cool shell produces a strain, which causes the ends to bulge out; or if the ends are made rigid, the strain sets up a contortion in the tube, which causes furrowing of the plates by making the iron softer or more susceptible of corrosion in certain lines of strain. Notwithstanding these drawbacks however this form of boiler is an excellent one.

Many modifications in the forms of boilers have been made to enable the manufacturers to use the waste heat from various processes, especially from the making of iron. The plain cylindrical boiler has been used in this way, with sometimes as many as eight puddling furnaces made to work upon one boiler. One of the earliest special arrangements for this purpose was the Upright boiler with central tube, shown in Fig. 73, Plate 55, which was originally made for two furnaces; and about 7 feet diameter and 16 feet high. The size has since been increased to 10 feet diameter and 28 feet high, as shown in Fig. 74. These boilers are made for one, two, three, or four puddling furnaces; and consist of a cylinder with spherical ends, standing upright, with a central tube from the bottom to about half the height, into which the side tubes join. The heat from each furnace plays over a portion of the shell, and then passes through the side tubes and down the centre tube into the underground flue to the chimney.

These boilers have many good points: there is great heating surface; and the shell being heated all round does not strain the plates and seams by unequal expansion so much as in the horizontal plain cylindrical boiler heated only at the bottom; and as both ends are spherical there is no alteration of shape under internal pressure. Moreover in consequence of the upright position of the boiler a safe depth of water can easily be maintained, and yet the steam is taken off so high above its surface that there is little priming; and

Some of the most fatal explosions of these boilers have arisen from careless construction. Such was the case in an explosion at Dudley in 1862, shown in Fig. 9, Plate 45, where the crown plate forming the top of the centre tube was attached to the sides of the tube by so slight an angle iron, as shown enlarged in Fig. 10, that the pressure of steam on the flat crown plate fairly sheared the angle iron through, and allowed the plate to be blown down the centre tube into the chimney flue, whereupon the boiler was violently thrown off its seating by the reaction of the issuing steam and water thus liberated.

The double-tube horizontal boiler is also used in connection with iron-making furnaces in many places, one furnace working into each tube. Although by this arrangement the boiler can be placed a little further from the workmen, some very fatal explosions have happened to such boilers, as at Masborough in 1862.

Single-furnace boilers have been much used in the form of a single-tube boiler standing on end, as shown in Fig. 75, Plate 55, with the flame passing up the tube, which is continued in the form of a chimney on the top of the boiler. The tube passes through the steam at the top, so that the plate is not protected from overheating by contact with water; and this has caused explosion in some instances, although the tube has been lined on the inside with firebrick to shield the plate from the flame. Another great disadvantage of this Chimney boiler is that the space between the tube and the shell is so narrow that it is almost impossible to examine or clean it internally.

A further arrangement for a single-furnace boiler is the Elbow boiler, shown in Fig. 71, where the two difficulties mentioned in the previous boiler are avoided.

Many internally fired upright boilers of various shapes have been constructed to suit various purposes. One of a large size that has been at work many years is shown in Fig. 76, Plate 55, with an internal fireplace and a suspended cone and cross tube for increasing the heating surface. This boiler is set in brickwork in such a way that the heat passes through the side tubes and round the exterior shell before going off to the chimney.

A very fatal explosion at Stoke-upon-Trent in 1863 resulted from an attempt to work a boiler of somewhat the same general form, but without the same careful attention to the details of construction. This boiler is shown in Fig. 12, Plate 45; the internal fireplace is of conical shape, 4 ft. 6 ins. diameter on the top and 6 ft. 10 ins. at bottom, and was joined to the external shell by a flat annular bottom. Almost the first time it was worked at high pressure the conical fireplace collapsed, breaking off at the seam at the top of the cone, and blowing down upon the grate, as shown in Fig. 13. The flat bottom was then left without the support of the cone and side tubes, and gave way all round the outside angle iron; and the top flew up a great height into the air, and fell a crumpled heap, as shown in the sketch. In this case the only wonder is that a boiler of such weak construction worked at all without explosion.

There yet remains to be noticed a very large and varied class of boilers that have been designed with the express object of avoiding explosion. Some of these, made of cast-iron pipes of small diameter, have already been referred to. When steam carriages were first constructed, boilers were tried made of a cluster of small pipes, set both upright and horizontally, connected with a general receiver and with each other by still smaller pipes. These were found to have such small circulation of water that they very soon burnt out, and also led to much priming. Afterwards narrow chambers made

this paper, as they are fully given in the published official reports of the government inspectors.

Among the forms of boilers designed to obtain very rapid generation of steam, combined with increased safety from explosion, may be specially named that consisting of a system of small pipes within a shell with an artificial circulation of water, and also the boiler consisting of a cluster of cast-iron spheres, both of which have been described at previous meetings of the Institution (see Proceedings Inst. M. E. 1861 page 30, and 1864 page 61); but neither has been much used in this country at present. The boilers also which consist chiefly of small tubes hanging down into the fire, with smaller tubes or other arrangements within them for securing a natural circulation, deserve mention, as they appear successfully to accomplish that end.

The principle of all these small boilers appears to be that only a small quantity of water should be contained in them, so that there should not be a reservoir of danger in the shape of a mass of highly heated water ready to be converted into steam if a rupture takes place: and it cannot be denied that this is an advantage. But on the other hand these boilers of small capacity, which evaporate their whole contents in a few minutes, are subject to new dangers from that very cause; and although admirably adapted for purposes where steam is wanted quickly on a sudden emergency, as in the case of fire engines, or where the generating power required varies each moment, as in the locomotive, they are for the most part ill adapted for ordinary stationary purposes, such as the mill or the colliery. They require constant firing and vigilant attention to the feed, and cannot be left for a time with safety like the ordinary stationary boilers. It has to be borne in mind also that the very reservoir of danger so much dreaded is also a reservoir of power, which assists in the steady maintenance of the machinery in motion. The large mass of water heated to the evaporating point, the heated brickwork of the flues, and the large fireplace, are so many assistances to regularity, and enable the man in charge to attend to his other duties without the risk of spoiling the boiler or letting down the steam by a few minutes' absence from the stoke hole. Steam

employers are found at present to prefer the known dangers of the large boilers to the supposed safety of small boilers, which they fear are troublesome in practice.

Many of the early boilers were rendered weak by the injudicious manner of arranging the seams. The longitudinal seams were made in a continuous line from end to end, as shown in Fig. 57, with the transverse seams also continued completely round the boiler, so that at the corner of each plate there were four thicknesses of iron. The crossing of the seams, as in Fig. 58, adds much to the strength, and also often prevents a rent from continuing forward to a dangerous extent.

It is scarcely requisite to mention the necessity of good material and workmanship to secure strength in a boiler, however perfect the design. If the plates are of weak or brittle iron, or imperfectly manufactured, they will never make a good boiler. Apart from the strain upon the boiler when at work, the iron has to undergo the strain of the necessary manipulation, shaping, and punching, during the construction of the boiler. If the plates forming the boiler are not well fitted to their places before the rivet holes are made, the errors have to be partially rectified by using the drift in the holes to an unwarrantable extent, and then using imperfect rivets to fill up the holes that do not correspond with each other; and the mischief is too frequently increased afterwards by excessive [redacted]

line, but these holes are made needlessly large. Steam domes are often so placed as greatly to weaken the shell of the boiler, the hole cut out of the plate being made the full diameter of the dome; and in some cases the domes or steam chests have been made square or rectangular, so as to weaken the shell still more, as shown in Fig. 14, Plate 46.

Manholes are often a source of danger, if not properly arranged and duly strengthened. Even in very small boilers they are often placed with the longest diameter in the longitudinal direction of the boiler, so that the shell is greatly weakened, as in the sketch, Fig. 17, Plate 46, of an exploded boiler at Walsall in 1865. This boiler was 5 ft. 3 ins. long and 2 ft. 6 ins. diameter, and yet the manhole was 18 inches by 13 inches, and placed within a few inches of one end. The end was fastened in by angle iron, which was not welded, and consequently there was so little strength at the small portion of the shell between the end and the manhole that it gave way and liberated the end and the manhole lid, after which the main body of the boiler was thrown by the reaction across several streets to a great distance.

A somewhat similar injudicious arrangement of the manhole is shown in Fig. 16, Plate 46, where a manhole 17 inches by 14 inches was cut out of the flat top of a steam dome only 2 ft. 6 ins. diameter, without any strengthening ring to compensate for it. The repeated strain of screwing up the manhole lid, combined with the pressure of the steam, caused the lid to force its way out through the plate and blow away. This explosion occurred at Birmingham in 1865.

The preceding examples have shown how explosions often result from faults in the construction of boilers; and the following instances illustrate the explosions caused by mischief arising during working. A boiler perhaps more than any other structure is subject to wear and tear; and let it be worked ever so carefully, it will seriously deteriorate. The wonder is, considering the work they have to perform, that so many boilers are found which have worked twenty, thirty, or even fifty years without explosion. The terms wear and

tear however are too vague for this subject, and the mischief met with must be considered under distinct heads.

There is no doubt that the thing most to be dreaded for boilers is corrosion; because when the plate is once thinned, it cannot be strengthened again, but must remain permanently weakened. Corrosion the more deserves attention because it is easily detected by moderate vigilance, and can generally be prevented by moderate care, or by the boilers being so arranged that they can be readily examined in every part. Corrosion has been the direct and unmistakable cause of a very large proportion of the explosions that have happened: it occurs both inside and outside the boiler, according to circumstances, and attacks the iron in various ways and in different places.

Internal corrosion sometimes takes place from bad feed water, and its effects are different in extent in the different parts of the same boiler. It very seldom thins the plate over a large surface regularly, but attacks the iron in spots, pitting it in a number of holes. These are sometimes large, as if gradually increasing from a centre of action; and sometimes small, but so close together as to leave very little more space whole than that which is attacked. A very curious example of the latter is exhibited to the meeting, and shown in Figs. 27 and 29, Plate 48, cut from the lower part of the shell of a large tubular boiler externally fired. The corrosion was [redacted]

over the area DDD, where unprotected by scale. The protection afforded by scale against occasional corrosive feed water is worthy of notice. In the two specimens exhibited it is seen that the protection has been perfect where the scale has not been chipped off; and the edge of the sound part projects over the hollow, as seen in the full size sections, Figs. 29 and 30, the corrosive water having eaten away a larger area beneath than that through which it first entered the surface of the iron.

Internal corrosion is frequently observed where boilers are fed from canals or streams in the neighbourhood of chemical works from which corrosive matter is discharged at intervals into the water. The corrosion takes place in isolated spots, but causes deep holes; which seems to be accounted for on the supposition that the scale previously upon the plate cracks during the cooling of the boiler for cleaning, and forms a blister, so that a piece of about 2 inches area is raised slightly from the iron. When the boiler is again put to work, this blister becomes filled with the corrosive water, which is held there without circulation and causes corrosion. When the boiler is again emptied these blisters may be seen, and if broken show the blackened water and the injured surface. In future working each of these blisters forms a constant unprotected point for attack. It is frequently seen further that such corrosion is arrested if water be used which deposits scurf; but fresh blisters and renewed corrosion will result from a return to the use of the bad water.

The internal corrosion called furrowing has proved a frequent cause of explosion, especially in locomotive boilers. It differs from other corrosion by being in deep narrow continuous lines with abrupt edges. It will sometimes go completely through a plate; and is found where a sudden change of thickness occurs, either along the lines of the seams, or opposite the edge of angle-iron attachments. This effect is supposed to be due to the alternate springing of the plates under each variation of the pressure or temperature, causing the line of least resistance to receive a strain somewhat similar to that produced by bending a piece of iron backwards and forwards for the purpose of breaking it. This line of injury

is exposed to constant attack from corrosion, because the scurf is always thrown off from it.

External corrosion is a far more frequent cause of explosion in stationary boilers; and it arises from many causes. The most frequent cause, although the most easily detected, is leakage from the joints of the fittings on the top of the boiler, which are too frequently attached by bolts instead of rivets. This evil is much increased when the boilers are covered with brickwork, which holds the water against the plates, and hides the mischief from observation. It is astonishing to find how much damage is allowed in this way to go on without attention, until the tops of boilers are corroded so thin that little holes burst through. These are sometimes found stopped with wooden pegs or covered by screwed patches of plate, either of which cause leakage that hastens the mischief, as shown by the sample exhibited. Boilers exposed to the weather will of course become corroded like anything else made of iron and not painted; and yet so much mischief is sometimes caused by leakage beneath improper covering that exposure may almost be said to be the smaller evil of the two, as it is better to see what is going on than to rest in false security. No covering will be found cheaper or better in the long run than a roof, which prevents the loss of heat by exposure, and yet allows free access to all the [redacted]

beneath the ashes, in conjunction with the corrosive matter from the ashes themselves, thinned the tops of the boilers to a dangerous extent in less than two years. A sketch of the corrosion caused in this instance by covering with ashes is shown in Figs. 31 and 33, Plate 49. Similar mischief has been noticed in boilers covered with sand, as shown in the sketch Figs. 32 and 34, which represents an instance of corrosion after eight years' working; although nothing forms a better covering than sand for preventing loss of heat by radiation. In both these examples it will be seen that the corrosion has continued until the thickness of the plate has been so eaten away that a hole has been burst out at SS. A very good covering is formed by brickwork in cement; or various cements made for the purpose, which adhere to the surface of the plate and yet show leakage; or such materials as sacking or felt; or sheet-iron casing leaving about 6 inches of air space all round the boiler. But all these have the great objection that they hide the boiler from inspection, except by the expensive process of removing the covering; and in this way dangers that have caused explosion have remained hidden from observation.

Explosions have also taken place from general corrosion of the surface of the boilers in the flues. A new boiler which was set on sidewalls built upon a foundation of porous rock was found to have become corroded all along the bottom in less than two years, owing to the dampness which rose from the foundations causing a constant presence of vapour. The corrosion was peculiar, and more like that found on old iron left for a long time in a damp place; for the iron plate fell to pieces when touched, and large flakes could be raised from the surface, and the greater part of the thickness of the plate could be removed with the fingers. Somewhat similar corrosion had taken place in a boiler which exploded at Loughborough in 1863; the bottom of the shell became rent at the corroded part, and as the fracture continued spirally round the boiler several times, nearly all the shell was peeled off in the curious manner shown in Fig. 15, Plate 46. The explosion shown in Fig. 19, which occurred at Leeds in the present year, also arose from corrosion of the bottom of the boiler.

The greater part of the corrosion found in the side flues of boilers is caused by the leakage of seams. Many boilers are emptied for cleaning as soon as work is over on Saturday night, and long before the brickwork of the fireplaces and flues has cooled; and consequently the boiler, having no water in it, is made much hotter than it ever is in working, and the seams are injured and sprung and the rivets loosened by the extra expansion so caused. This is sometimes done intentionally, in order to loosen the scale by the greater expansion of the iron than of the scurf. When the boiler is again set to work, the seams and rivets leak and cause that corrosion which is called channelling. This has been observed to occur to such an extent that all the seams in a boiler have been seen thus corroded; and the same has sometimes been found in all the boilers in a large manufactory. Specimens of this channelling are exhibited to the meeting. One in particular, shown in Figs. 38 and 39, Plate 50, deserves attention, as it shows the effect of a jet of steam and water from the leaking rivet R, in cutting a series of channels into the plate along the course of the dotted lines EEE, and producing a hole in the plate at S. This corrosion had been going on for about four years, but was in a part of the boiler seldom seen in ordinary examination. Many explosions have resulted from this form of corrosion; for when a rent is once made, the fracture continues along the thinned channel of the plate.

[redacted]

to take again its proper proportion of the weight of the boiler. Cases have been met with where the shape of the bottom of large boilers has been quite altered by such means. The brackets on the sides of heavy boilers have not only been strained so that the rivets or bolts have leaked and caused corrosion, but they have also bent or cracked the side plates of the boiler. The bracket shown at B in Fig. 14, Plate 46, made of only an angle iron with a piece of plate attached, is especially liable to cause injury if the brickwork is not rebuilt close up to the angle iron, as the leverage is so great. This is avoided by the better form of bracket shown at C, consisting of an elbow of flat bar-iron rivetted at top and bottom to the boiler.

In the old balloon and wagon boilers the angle where the bottom joined the sides scarcely ever remained sound for long when in contact with the brickwork, and many of those that exploded have been found almost corroded through where they stood upon the brickwork. The explosion before alluded to and shown in Fig. 7, Plate 44, was caused by corrosion of the bottom of the boiler where it was set on the brickwork. Many boilers are so set that the brickwork of the flues is made to follow the shape of the boiler, with as little space between as possible; but the slight advantage gained in increased heating effect is far outweighed by the impossibility of getting into the flues for examination. It is only by having the flues sufficiently roomy that proper examination can be made, and that the indications on the brickwork of leaking can be seen and remedied, and corrosion arrested. A remarkable case of corrosion occurred in a boiler with an oval shell, set upon a middle wall. The flues were too narrow for a man to enter, and a leak in the bottom was only discovered by the boiler nearly running empty while the engine pumps were standing for a short time. It was subsequently found that the whole bottom where it rested on the wall was extensively corroded in a continuous line, and that explosion was only prevented by the numerous stays across the bottom to compensate for the oval shape. Fig. 24, Plate 47, shows the position and extent of the corrosion, and the plate was completely in holes at the parts indicated by the black marks. This corrosion was supposed to have been going on for about three years.

It is sometimes asserted that corrosion cannot be the cause of an explosion, because the corroded place would simply give way and let off the steam harmlessly, or at least the boiler would not be displaced from its seating. When the corrosion is only local, and surrounded by sound plates of sufficient strength to arrest the extension of the fracture, this may be the case, as in an explosion at Sheffield in 1865, shown in Fig. 25, Plate 47, where a piece of plate was blown out on one side of the boiler, allowing the steam and water to escape without displacing the boiler; the thickness of the plate at that part had been reduced to 1-8th inch by corrosion in about $1\frac{1}{2}$ years, which had been caused by leakage at the seams from inefficient repair with bolts instead of rivets, and also from the moisture having been allowed to be kept against the plate by the brickwork. But even under such circumstances, if the piece blown out should be from the bottom, the whole boiler may be thrown a great distance by the reaction of the issuing steam, as in an explosion at Leeds in 1865, shown in Fig. 23. If the corrosion extends for any length, the first rent is almost sure to continue until a complete explosion is the result. Several of the small models exhibited to the meeting show the line of fracture in various cases of explosion. One shows the appearance of a plain cylindrical boiler after explosion caused by corrosion along the whole length where it rested on brickwork; this explosion occurred at Wigan in 1865, and [redacted]

an explosion at Bilston in 1863, where a large plain cylindrical boiler 9 ft. diameter was heated by three large fires placed side by side along the bottom; and a large "pocket" burst out over the third grate, and scalded the attendant to death. A similar pocket in a boiler 4 ft. 6 ins. diameter, which exploded at Dudley in 1864 after having been at work six weeks without cleaning, is shown in the transverse section, Fig. 37, Plate 50. In this case the scurf had filled up the circle of the boiler to a depth of 3 inches at the bottom, as shown in the drawing, and was of a very hard description; and the boiler plate was bent out in a gradual curve, and thinned out to about 1-16th inch, the original thickness being ½ inch.

The whole bottom of a boiler is sometimes injured and the plates buckled and the seams sprung from the accumulation of mud. One case may be mentioned where the water was very full of mud, and the boilers were worked day and night during the week, but stopped for several hours on Sunday, during which time the deposit of mud was so thick that it did not get thoroughly disengaged again from the bottom when the boiler was set to work, but hardened into a mass. Although many of these pockets and injuries to the plates may occur without serious damage, they sometimes cause that first rent which destroys the equilibrium of the structure and leads to explosion. Some of the specimens of scurf exhibited to the meeting show that their thickness is made up of small chips carelessly left after cleaning or fallen from the sides of the boiler, as seen in Fig. 36, Plate 50; or from cotton waste or other matter left in the boiler and forming a nucleus for the scurf to accumulate upon. Other specimens show that foreign matter must have been put into the boiler to stop leaking.

Accumulations of scurf in the feed pipes at the point of entrance into the boiler have also caused explosion by stopping the supply of water. The same result is caused by the freezing of the water in the pipes which are exposed; and each winter one or two boilers are injured or exploded from this cause, especially small household boilers placed behind kitchen grates. Scurf cannot be considered so great an evil as corrosion, since it can be removed; and if this is done in time, the boiler is restored to its original condition.

The advantage of a pure water which does not deposit scurf is so great for the supply of boilers that it is always worth while to go to considerable expense for obtaining it; or to take some steps for purifying the feed water as much as possible. If it is only mud mechanically suspended, which would deposit by gravity on the bottom of the boiler, frequent use should be made of the blow-off apparatus. If the impurity is light enough to be carried to the surface in the form of scum, the blow-off apparatus should discharge from the surface of the water as well as from the bottom. If the impurity is chemically suspended in the water, some one of the many substances which form the refuse from various manufactures and which may contain suitable ingredients should be used to counteract the effect of the impurity. Common soda will answer the purpose perhaps better than anything else. It must not be forgotten however that the blow-off apparatus must afterwards be used more frequently, to rid the boiler of the foreign matter, or the mischief will be increased. In marine boilers constant attention is necessary to get rid of the saline deposit; and in stationary boilers using impure water an equally systematic attention is needed to get rid of the earthy deposit.

Perhaps no cause of explosion is oftener mentioned than shortness of water, and this is not unfrequently coupled with turning on the [redacted]

runs rapidly empty, from the breaking of the blow-off pipe or any such cause, it will simply get red-hot and sink out of shape upon the fire, as may often be seen; but no explosion would happen. If the water only falls gradually, as it would if the feed were turned off and evaporation continued, the parts exposed to the fire would get overheated as the water left them. If the subsidence of the water were very slow, those parts might get red-hot, and so much softened and weakened as to be incapable of bearing the pressure, when an explosion would take place, as at Smethwick in the present year, where the flues were set above the water line, as shown in Fig. 26, Plate 47.

If however the water were turned on again before the overheating had gone so far, and the feed pipe were as usual carried down to nearly the bottom of the boiler, the water would gradually creep up the heated sides and cool the plates, the heat of which would not be sufficient to cause greater evaporation than the ordinary safety valves would carry off. The danger would not arise so much from the excess of steam generated by the heat accumulated in the heated plates of the boiler, as from the injury and strain that would be caused to the plates by the undue expansion and sudden contraction, especially as this action would take place on only a portion of the boiler. A singular case bearing on this point may be mentioned. A four-furnace upright boiler, like that shown in Fig. 74, Plate 55, happened to run so nearly empty, through the accidental sticking of the self-acting feed apparatus, that the level of the water sank to the top of the hemispherical end forming the bottom of the boiler. The feed apparatus then became released of itself, and the feed being turned full on, the water gradually rose until the whole occurrence was only discovered by the leaking at the seams that had been sprung, which caused so much steam in the flues as to stop the working of the furnaces. The overheating had been sufficient to buckle the plates, and in one place a rupture had almost commenced; but there was no explosion. By way of direct experiment upon this point, boilers have been purposely made red-hot and then filled with cold water, without causing explosion.

It has been supposed that boilers sometimes explode from overheating without the water level being below the usual point, or without the accumulation of scurf previously alluded to, but simply by the rapidity of the evaporation from an intensely heated surface causing such a continuous current of steam as to prevent the proper contact of the water with the heated plate. Such has been the cause assigned for the explosion of a three-furnace upright boiler at Birmingham in 1865, shown in Fig. 20, Plate 47. A piece of plate about 3 ft. by $1\frac{1}{2}$ ft. was blown out of the side, at a place where an enormous flame impinged continually. The plates had first bulged out, and then given way in the centre of the bulge, each edge being doubled back and broken off. There was no positive evidence as to the water supply; but the crown of the centre tube, which was much above the bottom of the part blown out, remained uninjured.

A somewhat similar case was that of a large horizontal boiler at Kidderminster, the tube of which collapsed in 1865, as shown in Fig. 21, Plate 47. It was heated by four furnaces, one of which worked into the tube, one under the bottom, and one on each side; and all the furnaces worked into the same end of the boiler. The tube was found to have partially collapsed at that end, and the top had dropped 11 inches. This was repaired in the first instance, but was afterwards again found injured by overheating, although not so seriously. It is very probable that the extremely rapid ebullition

[redacted]

working than to original bad quality. Of course this is not always the case, as the injury done to plates by overheating has been already explained. Pieces of plate have in some cases been erroneously pronounced to be deteriorated by work, which have been taken from situations in the boilers where they were not exposed to any action of fire that could cause overheating; and therefore in reality the injury could only have taken place when the boiler was being made, by burning the iron in bending it to the required shape. A frequent cause of fatal injury to boilers is injudicious repair, whereby the crossing of the seams is destroyed, as in the explosion at Wolverhampton in 1865, previously referred to and shown in Fig. 8, Plate 44. Moreover the edges of the old plates, already tried by the first rivetting and the subsequent cutting out of the rivets, are frequently strained again by the use of the drift to draw them up to the strong new plates; and many a seam rip is thus started which ultimately causes explosion.

Many explosions have been caused by the want of proper apparatus for enabling the attendant to tell the height of the water and the pressure of the steam, and also by the want of sufficient apparatus for supply of feed water and escape of steam, or by the failure of one or other of these; but such explosions can only be referred to generally in the present paper. The mountings on a boiler are usually so open to observation, and the importance of having them good and efficient is so universally acknowledged, that much remark is not needed. Mention has already been made of the sticking of self-acting feed apparatus as a cause of mischief, and similar failures of floats and gauges have constantly happened; but this should by no means be considered to condemn self-acting apparatus, either for assisting in the steadiness of working, or for giving warning of danger. The apparatus however should be relied on for assistance only; and an attendant cannot be called careful who leaves a boiler dependent on such apparatus without watching. The self-acting principle has been seen by the writer applied in a novel and useful way in a recording pressure gauge, which proved the more interesting as it had shown the actual pressure of steam at the time of the explosion of one of the boilers with which it was connected.

Among the numerous boiler explosions that have been attributed to over-pressure through deficient arrangements for escape of steam, in many cases the safety valves have been placed on the steam pipes in such a manner that the communication with them was cut off whenever the steam stop-valve was shut, which is just the time when the safety valves are most wanted. Safety valves are too often found needlessly overweighted; and it is believed that many boilers are constantly worked with safety valves so imprudently arranged and weighted that they could not carry off all the steam the boilers would generate without a very great increase of pressure.

It is concluded that enough has now been said to show that boiler explosions do not arise from mysterious causes, but generally from some defect which could have been remedied if it had been known to exist. It only remains therefore to consider what is the most ready and efficient way to discover the true condition of a boiler. It has been maintained that this end is best accomplished by what is called the hydraulic test, in which a pressure of water is maintained in the boiler for a given time at a certain excess above the working pressure. This test is undoubtedly useful so far as it goes, and is perhaps the only one that can be applied to boilers with small internal spaces, such as locomotive boilers, not admitting of personal inspection over the whole of the interior; and it is also [redacted]

specially important that facility for examination should be made a consideration in selecting a construction of boiler. Permanent safety should be considered as an element of economy, in addition to its still higher importance in reference to the preservation of life.

Mr. MARTEN exhibited a large collection of specimens of corroded and fractured plates from boilers that had exploded, together with models showing the construction of some of the exploded boilers and the results of their explosion. A set of elastic models of different constructions of boilers were also shown, by means of which the effect of over-pressure of steam in altering the shape of the boiler and thereby leading to explosion was clearly illustrated.

Mr. W. FAIRBAIRN fully concurred in the views advanced in the paper that had been read, as to the importance of periodical inspection as a means of preventing steam boiler explosions, and he considered that was the only way in which safety could be effectually ensured. In the case of the Manchester Boiler Association, with which he had been connected from its formation ten years ago, the practice referred to in the paper of careful inspection had been carried out from the commencement, and also that of collecting records of every particular connected with boiler explosions that occurred within the cognizance of the Association. During the ten years of its operations, only four explosions had occurred of boilers inspected by the Association, causing the loss of three lives; and this exemption from accident was entirely due, he believed, to the periodical inspection of every boiler once in every three months; for during the same ten years the explosions of boilers not inspected by the Association had caused the deaths of 500 or 600 persons, and serious injury to nearly double that number, making an average of 5 persons killed per month.

Having witnessed the gradual increase of steam pressure in stationary boilers during the past thirty years, from the original 7 lbs. pressure in the old Boulton and Watt boilers up to the present pressures of from 40 lbs. to 70 lbs. and 80 lbs. in many factory engines, he was strongly of opinion that there were certain circumstances connected with the employment of these higher pressures of steam which were not yet fully appreciated and practically attended to. This appeared to be particularly the case in reference to the remarkable circumstance of grooving that was supposed to be produced by oxidation along the edges of the joints in boilers working with the higher pressures, so that the metal of the plates became eaten away along the joints until the thickness was frequently reduced in some places to less than 1-8th or 1-16th inch; and in locomotive boilers working at still higher pressures this grooving action of the corrosion took place with still greater rapidity. The effect was probably produced by causes both chemical and mechanical, the former arising from the water with which the boiler was fed, and the latter from the construction of the boiler itself and the strains to which it was subjected by alternate expansion and contraction in working.

Another fruitful source of explosion was the collapse of internal tubes, both in single-flue or Cornish boilers and in double-flue or Lancashire boilers; and he believed almost as many explosions took place from the collapse of tubes as from the tearing of the outer [redacted]

that so simple a remedy had not been applied, as he believed the use of stiffening hoops round the internal tubes was now generally adopted in the Lancashire district, and this plan was particularly important in boilers having large and long tubes of 35 to 40 feet length and upwards. The internal flues had also been strengthened by the addition of small transverse tubes extending across the flue from top to bottom; but though the heating surface was thereby increased, so that more steam was generated, he thought there was no cheaper and better construction in the long run than the simple two-flue boiler. He hoped those principles of construction would become generally adopted that would admit of greatly increased pressures of steam being employed, with reasonable certainty of freedom from the lamentable results which followed in the train of boiler explosions.

Colonel KENNEDY considered they were greatly indebted to the author of the paper for the laborious attention he had given to the subject, and the very valuable information he had collected in reference to the causes of explosion in stationary boilers, which he had no doubt would be the means of directing attention also in other quarters to the explosions of locomotive and marine boilers. From the explanations given in the paper respecting the various causes of explosion, it was clear that much of the injury and loss of life which had hitherto been occasioned by boiler explosions might in future be prevented by careful inspection of steam boilers; and the obscurity in which the causes of so many explosions had been enveloped might henceforth be dispelled by proper examination, and the real causes of such accidents might in almost every instance be elucidated.

Mr. F. J. BRAMWELL remarked that it would appear, from the comments made in the paper upon the different descriptions of stationary boilers which had been noticed, that there was not any one kind of boiler which was considered entirely satisfactory; and from the several considerations that had been advanced in reference to the constructions of boilers it appeared that, so far as any preference was entertained, it was in favour of the plain cylindrical boiler with hemispherical ends, fired underneath, and fixed so as to

allow of complete examination of its entire surface at any time, and not having any covering on the top to prevent loss of heat by exposure. This seemed by no means a satisfactory result to arrive at, as he believed such boilers must always be wasteful in consumption of fuel, and liable to injury at the bottom by deposit of scurf upon the plates immediately over the fire. His own opinion was much more in favour of the Lancashire or double-flue boiler, which was perhaps in most general use for manufactories; for there was a greater amount of heat obtained with the same consumption of fuel from the internal fire situated inside the flues, as contrasted with an external fire playing upon the shell of the boiler: moreover the deposit could accumulate in the comparatively cool space below the flues without causing injury to the bottom of the boiler from overheating. There was also a fair amount of water space and steam room in this boiler, to serve as a reservoir for preventing any very sudden fluctuations in the steam pressure in case of negligent firing; and when the flues were properly stayed by external strengthening rings, there need be no reason for fearing explosion by collapse of the flues. Allusion had been made in the paper to boilers holding only a small amount of water, so as to lessen the disastrous consequences of an explosion and prevent any serious damage being done by such an accident; and some boilers of that class had doubtless proved completely satisfactory in this respect and highly successful in rapid generation of steam, particularly with the

exhaust steam from the engine were passed into a condenser, it would be found that the amount of water deposited in the condenser was much more than that due to the steam employed in the engine, showing that a considerable quantity of water must have been carried off from the boiler mixed with the steam, owing to the violent ebullition of the water in the boiler. In these cases therefore he considered the only correct way of arriving at the actual evaporative power of the boiler was by the employment of a condenser in connection with the engine; by which means not only could the amount of water brought over be ascertained, but the heat given out could also be measured, and thus the quantity really evaporated and that carried over by priming could be separately arrived at.

With regard to the covering of stationary boilers, he was surprised that the use of sand for the purpose had not been spoken of more favourably in the paper, as he had himself employed it constantly for covering boilers and had found it a very satisfactory means of protecting them. The sand was itself a very good non-conductor of heat, and it was cheap, and easy to be removed with a shovel at any time for examining the boiler plates, and in this respect decidedly superior to more costly coverings which could not be readily removed. Any droppings of water upon the sand covering became absorbed by it, as by a sponge, without penetrating so far as to reach the boiler plates, if a proper thickness of sand were used; and the moisture was afterwards evaporated by the heat from the boiler. On these accounts he had been led to consider sand the most advantageous material that could be employed for covering stationary boilers. The feeding of boilers ought no longer to present any difficulty; for if the Giffard's injector were applied to every boiler or set of boilers, in addition to the present feed pumps, the regulation of the feed in stationary boilers would always be absolutely under control, and could be adjusted to correspond exactly with the quantity of steam required.

Mr. H. Maudslay remarked that the voluminous and authentic records contained in the paper formed a most valuable contribution to the Proceedings of the Institution, and the careful manner in

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which the information had been compiled and illustrated further enhanced its value; and they were greatly indebted to the author for having prepared the paper. A very useful summary had been given at the commencement of the paper, not only of the number of explosions that had occurred from the different causes which led to such accidents, but also of the number of explosions that had taken place with the different constructions of boilers in general use; and he had no doubt that the continuance of such a system of classification would lead to beneficial results in the prevention of explosions for the future. As the subject of the paper was the explosions of boilers, it was of course unavoidable that all the instances adduced as illustrations in the paper presented some unsatisfactory features, through the existence of which a failure of the boiler had either actually taken place, or might be expected to occur unless effectually guarded against by proper inspection; and it would remain for the balance of advantages or disadvantages attending any particular construction of boiler to be determined by the special circumstances of the situation and working in the particular case under consideration.

Mr. W. Richardson observed that among the specimens exhibited of fractured boiler plates he noticed one which appeared to be taken from the bottom of the shell of a cylindrical boiler, where the fracture had run along one of the transverse circular seams through [redacted]

bottom of the boiler would put a strain of compression upon the plates in the bottom, and the rent must of course have been occasioned by tension. He thought the cause was one which was often met with, particularly in plain cylindrical boilers, namely an injudicious mode of supplying the feed, the cold feed water being delivered into the boiler in an undivided stream near the bottom, or falling direct to the bottom by its greater specific gravity, whereby the boiler bottom was suddenly cooled at one part and caused to contract violently, while the rest of the shell remained heated and expanded; then the strain produced by the contraction would of course run to the weakest part of the boiler bottom, and a fracture would ultimately be produced by the repeated action of the strain at each time of turning on the feed again after it had been shut off for an interval. In order to obviate this difficulty he considered the feed water ought always to be either heated before entering the boiler, or circulated through pipes inside the boiler itself, so as to be made sufficiently hot before being allowed to mix with the water in the boiler, in order to prevent any injurious effects from difference of temperature.

Mr. W. Waller said that he was personally acquainted with the case of the fractured plate exhibited, and the feed water had been heated before entering the boiler; and therefore he thought a sufficient explanation appeared to be that the boiler had on some occasions been emptied by blowing off, while the flues surrounding it continued nearly red-hot, so that the whole boiler shell became very much overheated; and then the sudden cooling of the bottom by the free admission of cold air would have produced the severe strain of contraction which ultimately led to the rent. In some instances of similar rents in the bottoms of plain cylindrical boilers, in which the shell was made of Cleveland plates, but the bottom exposed to the fire of Low Moor plates, the cause could not be traced to any defect in the plates or the rivetting; and the idea was then suggested that it might be due to a different rate of expansion in the two qualities of plates used in the construction of the boilers. In order to ascertain the actual difference of expansion, two strips of plate, which he exhibited, one of Low Moor iron and the other

of Cleveland iron, each 47 inches long by $3\frac{3}{4}$ inches wide and $\frac{5}{8}$ inch thick, were rivetted together side by side at one end; and on then heating them together to a black red heat it was found that the Low Moor bar had expanded fully 1-16th inch less in length than the other. In one of the cylindrical boilers of 80 feet length this extent of difference would amount to as much as $1\frac{1}{4}$ inch, the consequence of which must be a severe tensile strain on the bottom of the boiler; and he had seen cases of as many as three or four seams ripped in the length of the boiler bottom, where the bottom had been made of Low Moor plates while the rest of the shell was of common iron.

Mr. L. E. Fletcher, Engineer of the Manchester Association for the prevention of steam boiler explosions, was sure it must have been no easy matter to collect all the details and arrange such a mass of information as was given in the paper that had been read; and it was clear that the subject of stationary boilers alone afforded ample material for a long paper, without going into the question of locomotive and marine boilers. From his own experience in investigating the causes of boiler explosions for some years past he was convinced that a great deal of unnecessary mystery and uncertainty had been attached to the subject, while in truth there was no mystery whatever connected with it; and he thought no progress would be made in the prevention of explosions until it was [redacted]

could keep it safe. The fractured plate exhibited from the bottom of a plain cylindrical boiler, with the rent following one of the transverse circular rows of rivets, illustrated the way in which such boilers frequently failed; and he thought the general cause of these failures was very simple, and was not sufficiently apprehended. It was evident that a rent in that situation could not arise from expansion of the boiler bottom, but must be produced by contraction, and he believed that contraction was continually occurring in ordinary working, from the firedoor being opened for firing; and then, the bottom of the boiler being very hot in consequence of the external firing, the rush of cold air every time the door was opened caused a sudden cooling and contraction of the bottom plates, the constant repetition of which frequently produced a rent across the bottom, exactly as in the specimen exhibited. On this account he did not think a boiler of that class could be kept safe for working, even when the feed water was heated; and with cold feed water the injury to the boiler bottom was of course still more rapid, as the cooling effect of the feed caused the bottom to contract and to be in tension from the sides of the boiler remaining expanded by heat. In all constructions of boilers the most effectual remedy for the evils attending cold feed water was to heat the feed before it entered the boiler, and to disperse it gently over a large area instead of delivering it all in at one spot. A seam-rent along a line of rivet holes, such as was seen in the specimen exhibited, was also sometimes caused by bad workmanship in the construction of the boiler, the rivet holes not being made to correspond with sufficient accuracy in the two plates, so that the rivets could not be put in fairly parallel and the holes had to be worked with a drift, whereby the iron was severely strained and small cracks were liable to be started at the rivet holes.

The upright boilers heated by puddling furnaces in ironworks, surrounded with brickwork, and placed in the busiest part of the works with numbers of men around, seemed as if specially contrived for doing as much injury as possible in case of an explosion. When one of these boilers exploded, it sent the brickwork flying like grape shot in every direction; and by the explosion of such a boiler he had known as many as twenty-five persons killed on the spot, while

the havoc produced was fearful. These boilers, like the plain cylindrical boilers, were indeed quite unmanageable in practice. The flames from the furnaces impinged direct upon the boiler plates; for although there might be a screen of brickwork at the bottom in the first instance, to protect the plates from being overheated, this was liable to fall away without being noticed, or even if its defective condition was known there was seldom time to stop the furnaces for repairing it; and the flames were allowed to play on the plates with full force, until an explosion was the result of the consequent injury to the plates.

Explosions arising from the collapse of internal flues could be entirely prevented by the addition of the external strengthening hoops that had been already referred to; while wasting of the boiler plates by corrosion could be detected by careful inspection in time to avert the danger. In connection however with explosions arising from both these causes it too frequently happened that the blame was laid upon the stoker, when he was only the victim and not the cause of the explosion. An instance of this sort was afforded by the explosion that occurred in 1865 at Abercarn in South Wales, which was stated to have been caused by shortness of water, and the blame was laid upon the engineman, whom however he believed to be quite innocent in the matter; for it was certain that the explosion, which arose through the collapse [redacted]

the safest. Although there must of course be a contest between the internal flues and the shell of this boiler from their different amounts of expansion, yet this was now fully understood, and successfully met by a proper mode of construction. It had been a difficulty of many years' standing, but was now fairly overcome and provided for. The proper way to construct all internal flues he considered was to bend the plates to a perfectly true circle, and weld the longitudinal joints instead of rivetting them, so as to avoid destroying the truth of the circle by a lap joint; and then either to add strengthening rings of T iron for securing the tube against collapse, or to flange the plates outwards at the transverse circular seams. By also taking care to secure elasticity in the end plates, and to leave sufficient water space between the flues and the shell of the boiler, the contest between them from difference of expansion was so far diminished as to be practically harmless, especially when the length of the boiler did not exceed 28 feet; and the boiler should be so set that the flame passed first under the bottom, after leaving the furnace tube, and last along the sides. With this mode of construction the thickness of the plates forming the flues might safely be reduced from the present ½ inch or 7-16ths inch to 3-8ths inch, or even to ¼ inch if steel plates were employed for the purpose; by this means the flues would be rendered lighter and less rigid in the longitudinal direction, and the thinner plates would be less liable to become overheated, in consequence of their conducting the heat more rapidly to the water. Lancashire boilers constructed in this manner could be safely guaranteed from year to year to continue in regular working without risk of explosion; whilst the plain cylindrical boilers and other boilers fired externally might be considered liable to risk from day to day.

The important conclusion therefore derived from the inspection of boilers in working and the investigation of all cases of explosion was that boiler explosions were not unaccountable, but originated always in some simple cause; and their prevention was not beyond the reach of engineering science, a periodical and careful inspection forming an essential condition for attaining the desired safety.

Mr. C. J. Galloway referred to the plan which had been mentioned of strengthening the internal flues of boilers by transverse conical tubes, placed vertically or obliquely across the flues, so as to form a communication between the water above and below the flues. This construction he thought had some advantages over the external **T** iron strengthening rings, as the transverse tubes not only strengthened the flues against collapse, but also greatly facilitated the circulation of the water and thus produced a greater equality of temperature throughout the boiler, whereby the contest arising from the unequal expansion of the flues and shell was mitigated. At the same time the additional heating surface afforded by the conical tubes increased the evaporative power of the boiler; and the tubes had been found quite satisfactory in working.

Mr. L. Olrick remarked that the very interesting and useful paper which had been read would be fully appreciated by all engineers, particularly as it contained a number of hints based upon the practical experience acquired by the author from an extensive acquaintance with steam boilers. One description of stationary boiler which had been alluded to in the paper, but had not come much under the author's practical notice, was that having a cluster of small vertical tubes suspended over the fire, for the purpose of obtaining the greatest possible amount of heating surface immediately over the fire. A similar construction had been tried some years ago, in which a smaller internal tube was inserted down the centre [redacted]

of the cooler water into the central tube, whereby a constant supply of water was maintained over the whole of the heating surface of the boiler. The result of this arrangement was that the boiler was exceedingly efficient in rapid evaporation, and in the steam fire-engines provided with these boilers steam was got up from water at 40° or 50° Fahr. to a pressure of 100 lbs. in $7\frac{1}{2}$ minutes. The objection that had been urged against the use of these boilers for ordinary stationary purposes was that, on account of the very small quantity of water contained in them in proportion to the heating surface, they could not be worked with so much safety, as any shortness of water in the tubes over the fire would cause them to become burnt, and an explosion would ensue. This difficulty however was readily obviated by employing a much larger water space when the boiler was used as an ordinary stationary boiler, and it then worked just as well as other boilers containing a large reservoir of water. One of these boilers was now used at the St. Katharine's Dock, London, in connection with Sir Wm. Armstrong's hydraulic machinery; it occupied a ground space of only $6\frac{3}{4}$ feet diameter and was about 12 feet high, and it evaporated 60 cubic feet of water per hour, which he believed was more work than any other boiler occupying the same space could do. In this case the boiler was fed with the water from the dock, which was exceedingly dirty and partially salt, and it had been doubtful whether the boiler would keep clean in working. It was found however that all the dirt was collected with the scale at the bottom of the water jacket provided for the purpose, which surrounded the firebox. Such a boiler might be pronounced practically safe from explosion, and no explosion had yet occurred with any of the boilers on that construction. An instance had occurred however about twelve months ago with another of these boilers, employed at Messrs. Siebe's ice-machine manufactory in London, where an explosion or collapse of the internal flue must inevitably have taken place had the boiler been one of the Cornish type. In this case the height of the water in the gauge-glass had been accidentally mistaken, the glass being thought to be full of water when it was really empty; and the consequence was that the water level in the boiler

became about 12 inches lower than the tubeplate, when the tubes over the fire, which were made with their bottoms soldered in, had the bottoms of some of them burnt out, and thus acted as safety plugs, causing the fire to be put out and thereby preventing further injury. This construction of boiler he therefore believed to be not only as safe but even safer than the ordinary Cornish or Lancashire boilers.

For the purpose of preventing over-pressure of steam he had endeavoured to increase the readiness of blowing off with the ordinary safety valves by increasing the inclination of the face of the valve seating to the valve spindle from the ordinary slope of 45° to 60°; but he had found the valves had a great tendency to stick, and in some instances the pressure in the boiler had risen to as much as 100 lbs. per square inch when the valve had been set to blow off at 60 lbs. He had also tried flat-faced safety valves having an annular bearing face from 1-16th to 1-8th inch wide, which was found to produce an improvement in preventing so great an excess of pressure in blowing off. The improved safety valve of Mr. Naylor (see Proceedings Inst. M. E. 1865 page 220) he had found to be very efficient in preventing over-pressure of steam; and on a boiler evaporating 60 cubic feet of water per hour one of these valves of 2 inches diameter had kept the steam pressure from rising under any circumstances more than 1 lb. above

[redacted]

to the very high evaporating power that the boiler could not be left unattended even for a few minutes without risk of the supply of steam becoming deficient and injury occurring to the boiler itself. Of course if the water space was increased to the same extent as in ordinary Cornish or Lancashire boilers, the rapidity of evaporation would be proportionately reduced, and would no longer constitute as at present the principal feature of these water-tube boilers. With regard to the different constructions of boilers, he had to remark that it had not come within the scope of the paper, as a record and analysis of boiler explosions, to recommend any particular construction as the best for general stationary purposes; but the preference had certainly not been given to the plain cylindrical egg-ended boiler, the disadvantages of which had been pointed out in the paper; while at the same time the double-flue or Lancashire boiler had not been passed over without a strong commendation on account of its many important practical advantages.

In reference to the covering of boilers, it had not been suggested in the paper that they should be left uncovered, but a roof had been strongly recommended as the very best covering. As regarded the use of sand as a covering, it would be remembered that at a former meeting of the Institution sand had been recommended for the purpose by Mr. Henry Marten (see Proceedings Inst. M. E. 1856 page 8); but subsequent experience had not confirmed the favourable opinion then expressed, and some boilers that had been covered with sand in consequence of the remarks then made had since been found so much injured by external corrosion that their tops had required renewal after only five years' working. Similar corrosion had taken place in a set of boilers covered with ashes, the tops of which had required renewal after only six years' working. Other instances of the extent of the corrosion both with sand and with ashes for the covering were shown in the specimens exhibited (Figs. 31 to 34, Plate 49). The internal channelling along the seams of a boiler caused considerable trouble, and he had known a stationary boiler grooved along every seam below the water level until more than half the thickness of the metal was gone, just as if a groove had been cut out of the plates with a gouge.

No reference had been made in the paper to locomotive and marine boilers, because his own experience had been principally confined to stationary steam boilers.

The President moved a vote of thanks to Mr. Marten, which was passed, for his valuable paper, and the great amount of labour he had bestowed upon its preparation.

The following paper was then read :—

DESCRIPTION OF THE REMOVING AND REPLACING OF THE IRON COLUMNS IN A COTTON MILL.

By Mr. WILLIAM FAIRBAIRN, of Manchester.

The improvements that have been effected in the machinery for spinning cotton have given rise to new conditions, new buildings, and new appliances, to meet the numerous changes that have taken place. The machinery for carding, roving, and spinning, has been renewed three different times within a period of less than sixty years, the old machines having been three times removed to give place to others of a more improved construction. The old narrow buildings of former days have consequently proved unequal to present wants, and it has been necessary either to alter the old mills to suit the new machinery, or to build new ones. The latter plan was occasionally preferred; but more frequently the spinning rooms of the old mills were altered so as to suit the new mules, which from their increased number of spindles had to be fixed in the longitudinal direction, instead of transversely as formerly.

Immediately after the invention of the mule by Crompton, or about the commencement of the present century, a cotton mill 45 feet in width was considered of proper dimensions for mules of 350 to 400 spindles. Two of these mules were looked upon for many years as the correct number for one man to work; and this might have been continued for a longer period, but for the invention of the self-acting mule by the late Mr. Roberts and others, which gave a new impetus to the spinning process; and in place of 400 spindles as formerly, the mules of the present day contain from 800 to 1000 spindles. This increase in the length of the mule required a corresponding increase of width in the mill; and hence arose the tower-like form of modern cotton factories, having as much as 90 to 100 feet and in some cases 120 feet width.

In the construction of modern mills no difficulty exists, as they are built to suit the machinery; whereas in adapting the old narrow buildings to the new mules it was necessary to remove the old mules and place the new ones in the opposite or longitudinal direction of the mill. In mills with wooden floors this was easily accomplished by removing one row of columns to admit a pair of mules in the middle; but in fire-proof buildings constructed with iron beams and brick arches the greatest possible care was necessary to be observed in effecting the desired alteration, as illustrated in the case forming the subject of the present paper, where 90 to 100 tons of arches and machinery had to be supported on two columns in each bay of a building eight stories high, the mill being kept working during the whole time the alterations were going on.

The objection to this operation on the part of the proprietors, Messrs. McConnel and Co., was that the columns could not be removed without cutting them, which might incur the danger of the whole of the floors above being "brought down by the run." Each column had in fact to be cut in two, taken entirely out, and new ones substituted at the required distances apart. As the particulars may be useful and interesting, the writer offers the following description of the process by which this object was successfully accomplished under his directions.

In Figs. 1 and 2, Plate 56, are shown longitudinal and transverse

admit a pair of mules in the longitudinal direction down the middle of the room. It was therefore necessary to move one row of columns nearer to the side wall, in order to give space for the two centre mules to work, as shown at A in the transverse section, Fig. 2. The other mules next the side walls had quite sufficient room, with the addition of a passage B, which extended along the side wall the whole length of the mill.

In the process by which these alterations were effected the first consideration was how to support the ends of the middle beams and arches at C C, Fig. 3, Plate 57, during the process of removing the columns from under them; and also how to support the middle beam permanently after the columns had been removed. This could not be done simultaneously throughout the mill when at work, as it would have involved a very heavy expense to support the ends of all the middle beams at once, with their superincumbent weight of 90 tons of brick arches and machinery upon each. Moreover it was essential that only one pair of the old mules should be stopped at one time, and only during the operation of fixing the new columns at D D and cutting out the old ones at C C.

The first thing to be done therefore was to prepare the new columns with their projecting brackets of sufficient length to reach beyond the ends of the wall beams, so as to support the ends of the middle beams at C C after the old columns were removed. As it was impossible however to remove that part of the column which went through the beams, it was necessary first to fix the new columns under the wall beams at D, and subsequently to cut out the old ones progressively as the work advanced from one end of the room to the other. The brackets on the new columns were made to project to about the same extent on both sides; but as they could not be extended the whole length on the side next the original columns until the latter had been cut out and removed, the bracket intended for supporting the end of the middle beam was left 12 inches short, so as to leave sufficient space for attaching the apparatus for cutting out the old column; and a loose end was afterwards bolted on, as shown at E, Fig. 3, Plate 57, which was made to fit the stump end of the old column after the column had been neatly cut off and removed.

Before removing the old columns, it was requisite to fix the new ones and make all the floors secure from bottom to top. This would have been comparatively an easy task provided the new columns had gone down to the bottom for foundations; but that was impracticable, as the two bottom rooms which contained the preparation machinery were not to be disturbed: the six floors above, which contained the mules, being those only that required alteration. The base of the new line of columns was therefore supported from the room F above the ground floor, Fig. 2, so as not in any way to interfere with the machinery below. Strong hollow wrought-iron beams G were fixed immediately under the cast-iron wall beams in the room F, and upon these were raised the new lines of columns through six floors to the top of the mill. One end of each beam G was fixed in the wall, and the other on a casting at H, Fig. 3, which embraced the column and transmitted the weight of the superincumbent arches to those below.

The new columns having thus been fixed in their places, the next process was to put a temporary prop under the middle beam, to support the arch above and to give room for cutting out the column before the loose end of the bracket could be attached for the final support of the middle beam. In this way, working from the top story downwards, as shown in Fig. 3, the process of cutting out the columns was entirely free from risk; for instead of supporting the whole of the arches in two bays from top to bottom of the mill,

carries the cutter J. The wheel is driven by the worm-shaft and pulley M, which receives motion from one of the driving shafts N, Fig. 3, in each room. The shank of the cutter is screwed to receive the ratchet-nut P, and by means of the finger Q the cutter receives the required advance equivalent to the thickness of the cut every time the ratchet passes the finger. The screwed shank of the cutter J is planed down flat on the top and bottom sides, as shown in Fig. 4, so as to hold the tool from turning in its socket.

By this means the column was quickly cut through at the top; and the width of the cut being sufficient to allow of the column being then canted enough for drawing the head from under the stump end cut off, the column was lifted out of the socket at bottom and removed. The loose end of the bracket having then been inserted with two strong bolts, as shown at E, Fig. 3, the end of the middle beam was thus supported with the same security as if the original column had never been disturbed.

Mr. Fairbairn remarked that the operation of removing the columns as described in the paper had appeared rather hazardous at first, as it had to be done while 300 persons were at work in the mill, and the weight of the iron girders and brick arches forming the floors amounted to 90 tons altogether. The work had however been performed with great care, taking one floor at a time and proceeding from the top downwards; and he believed the building was quite as safe now as before the alteration.

The President moved a vote of thanks to Mr. Fairbairn for his paper, which was passed.

The following paper was then read:—

ON AN IMPROVED MODE OF MANUFACTURE OF STEEL TYRES.

By Mr. JOHN RAMSBOTTOM, of Crewe.

In designing the mode of manufacture of Steel Tyres forming the subject of the present paper, the object aimed at by the writer was to reduce the waste of material in the process to so small an amount as to leave its effect insignificant upon the cost of production, and upon the calculation of the weight of ingot required for producing a tyre of given dimensions. Another object was to reduce the time of manufacture, thereby reducing the proportionate cost of plant by turning out more work in the same time.

The ingots are made from Bessemer steel, cast into the moulds shown in Figs. 1 and 2, Plate 59. They are in the form of a cone, 22 inches diameter at the base and 22 inches height, the corners at the base being rounded off. The apex of the cone is cut off at 6 inches diameter, and forms the opening for filling the mould. This is the size of ingot for making a 5 feet tyre, as shown in [redacted]

The bottom is 4 inches thick in the centre, and is protected from cracking by a wrought-iron hoop B shrunk round the outer edge. The centre of the base of the mould is made of fireclay, by inserting a plug C into a tapered hole in the bottom, to prevent the cast-iron bottom from being injured and burnt away by the stream of melted steel when poured into the mould at the top. This fireclay plug is readily renewed when required, being made from the worn out tuyeres of the Bessemer converting vessel.

As soon as the ingot can be removed from the mould it is reheated and then hammered laterally and endways in the manner shown in Figs. 3 to 6, Plates 60 to 62. The hammering is done by the 10 ton horizontal duplex hammer shown in the drawings, the two hammer heads D and E weighing each 10 tons, and moving horizontally towards each other. The cone is first hammered laterally all round its lower edge, as shown in Figs. 3 and 5, the object being to consolidate the skin of the metal and prevent cracking during the subsequent processes. The ingot is supported during the hammering by a carriage F specially constructed for the purpose of allowing the ingot to be rotated whilst being hammered. This carriage is made of boiler plate, mounted upon a cast-iron base-plate G; and the base-plate rests upon the centre bearings J J below, upon which it has a slight rocking motion, allowing the ingot to be adjusted between the two hammer faces, so as to secure the uniform action of the hammers upon it. The hand-lever H H connected with the base-plate G is held by the attendant during working, for adjusting the position of the ingot between the hammer heads. In hammering the ingot laterally, the two wrought-iron swage blocks I I, Fig. 3, are attached to the hammer heads; and a small turntable K, Figs. 3 and 5, supports the ingot at the top of the carriage F, allowing it to be rotated horizontally between each blow, by means of a fork which lays hold of the ingot like a spanner. This turntable is carried on a vertical centre pin, dropped into a cast-iron socket; and it is lifted out when the side hammering of the cone is completed.

The ingot is then canted over on its side, and hammered in the direction of its axis, as shown in Figs. 4 and 6, until it is reduced to

9 inches height, as shown in Fig. 15. The hammer head D, which acts upon the apex of the cone during this process, is narrower than the other head, and has the effect of spreading out the narrow apex more effectually than would otherwise be the case. In this position the cone rests upon the four rollers L L and M M contained in the body of the carriage F. Two of these rollers M M, carrying the large end of the ingot, are 10 inches diameter by 9 inches length and 1 inch tapered, and remain fixed in position. The other two rollers L L are 9 inches diameter and $1\frac{1}{2}$ inch thick, and are carried in a cast-iron frame which slides vertically within wrought-iron guides, and is supported by a long wrought-iron wedge N, Figs. 5 and 6. This wedge, which is 7 feet 10 inches long, is driven home at the commencement of the hammering, and is gradually drawn out so as to lower the supporting rollers by degrees, and accommodate their height to the increasing diameter of the centre of the ingot during the hammering. The rate of withdrawing the wedge N is regulated by the attendant, who has thus complete facility for adjusting the ingot constantly to its true level between the two hammers with as great accuracy as if he were holding it by hand. The taper in the two fixed rollers M M, Fig. 4, allows for the slight increase in diameter of the base of the ingot, which advances downwards towards the small ends of the rollers as the hammering proceeds. The ingot is continually turned round upon [redacted]

the other side, this process being repeated until the hole in the bloom is enlarged on both sides to the size of the base of the conical punch, as shown in Fig. 16. The flat hammer face P, which is prolonged on each side of the punch, as shown in Fig. 7, then acts upon the bloom, and hammers it down in thickness, the bloom being turned round horizontally between each blow. By this means the bloom is brought to 31 inches diameter and $5\frac{5}{8}$ inches thickness, with a centre hole 11 inches diameter in the middle, as shown in Fig. 17. The anvil block Q is made with a hole all down the centre, large enough to give clearance to the punch in its lowest position, as shown in Fig. 9; but in order to prevent the centre portion of the bloom from being driven down into this hole at the commencement of the work, the hole is at first contracted in size by a steel ring R, Figs. 8 and 10, dropped into a recess at the top. This ring is afterwards removed when the punching of the hole has been partly completed on one side of the bloom.

In order to afford facility for turning the bloom over quickly upon the anvil of the punching hammer, a swing frame S is employed having two centre screw pins, which seize the bloom a little below its centre of gravity. These screws are tightened up by hand for laying hold of the bloom, and after it has been turned over they are slackened back again, and the swing frame lies on the ground out of the way during the hammering. When in use the outer end of the swing frame is connected by a chain to the hammer head, as shown in Fig. 7, so that the frame and bloom are lifted by the hammer, and the bloom turns over by its own weight, thus requiring no crane. During the hammering the bloom is turned round horizontally upon the anvil by means of ordinary pinch bars.

The next operation is hammering out the bloom edgeways, in order to enlarge the centre hole, which is done upon the beck anvil shown in Figs. 11 to 13, Plates 65 and 66. The side of the anvil T is inclined at 20° to the vertical; and the beck iron U, which stands out at 81° to the side, projects 10 inches and is $11\frac{1}{2}$ inches diameter at the base. The bloom is rotated vertically between each blow of the hammer by means of a pinch bar V, Fig. 12, suspended by a

chain from the top of the hammer framing. After the hammering on the beck is finished, the bloom is laid flat on the top of the anvil and hammered all round, as shown in Fig. 13, whereby the slight increase of width produced by the spreading on the beck is hammered down to the final width of $5\frac{5}{8}$ inches, as shown in Fig. 18, Plate 67. After the completion of each process, any cracks which may appear on the surface of the metal are chipped out.

By this hammering the bloom is brought to 34 inches diameter, with the centre hole 19 inches diameter; and it is then finished in the circular rolling mill, the well-known ingenious invention of Mr. Rothwell Jackson, one of the Members of the Institution, which brings the bloom to the form and dimensions of the finished tyre, as shown in Fig. 19, by rolling it at the same time both outside and inside without altering the width. This machine completes the rolling of the bloom into a finished tyre at one heat, the time occupied being about $5\frac{1}{4}$ minutes in the rolling machine.

The whole of the above process for the manufacture of the tyre is effected in four heats after the original casting of the ingot, which is taken from the mould as soon as the metal has set, and is then reheated for the first time before being taken to the horizontal duplex hammer. The second heat is in preparation for the punching of the centre hole, after which the bloom is again reheated for the [redacted]

This mode of manufacture of tyres allows of all the material in the original ingot being used up in the finished tyre; a very trifling amount of metal alone is punched out in first forming the centre hole, and the material is afterwards simply displaced laterally and gradually worked outwards from the centre, as the hole is expanded from the beginning to the end of the process. The top of the conical ingot, instead of being cut off as a crop end of the full area of the ingot, as in the ordinary mode of manufacture from a parallel ingot, is reduced to only 6 inches diameter, which being in the centre of the ingot is at the part worked through by the punch, and remains at the inner side of the finished tyre, thus avoiding any risk of affecting the wearing face of the tyre. As another consequence of the very small area of the top of the ingot, the covering plate required in casting is so small and so thin that it is lost in the first reheating furnace by oxidation.

The saving of waste of material in this mode of manufacturing steel tyres has the important advantage not only of reducing the cost of manufacture, but also of allowing the total quantity of metal to be adjusted beforehand with great accuracy for the required size of tyre. Thus the 5 feet tyres, the size to which the dimensions of ingot previously given apply, are made from an ingot weighing 8 cwts., and the weight of the tyre finished from the rolls is a little more than $7\frac{1}{4}$ cwts.; so that the total loss by reheating in the process of manufacture is only 8 per cent. The required weight of ingot can therefore be calculated and provided for any given size of tyre; and the form of the ingot with the small area at top ensures a degree of uniformity not otherwise attained in the weight of the castings, as the whole extent of variation possible in the height of the ingot cannot cause any appreciable difference in the size of the finished tyre.

By this mode of manufacture of the tyres it will be seen that a very large amount of work is put into the ingot by the successive hammerings, before it enters the final rolling mill; and the effect of this in the writer's opinion is to cause a very considerable improvement in the quality of the tyres, rendering the metal mild and tough in a remarkable degree. The broken tyre that was

exhibited to the Members, when visiting Crewe yesterday, required nine blows from a weight of 21½ cwts. falling from a height of 22½ feet to break it.

Colonel KENNEDY was sure all the Members had been highly gratified by the excellent opportunity afforded them on the previous afternoon of witnessing the manufacture of the steel tyres at the Crewe Steel Works, and seeing the very admirable manner in which the whole of the operations were there carried out for the manufacture of locomotive work, together with the many important improvements that had been introduced. From the very valuable paper that had been read it would be seen with what complete success the Bessemer process had now been applied to the manufacture of tyres; and he should be glad to know some further particulars respecting the durability of the steel tyres in comparison with the best iron tyres, as he had always expected the material [redacted]

hesitation in adopting the Bessemer steel tyres if the cost were anything like as much as that of the cast steel tyres made of crucible steel, costing about £35 per ton. It was not any question of the quality of the steel tyres which retarded their adoption for railway carriages and wagons, but solely a matter of reduction of cost, as there appeared no reason to doubt that the steel tyres would have an advantage in durability over the present iron tyres. At the present time however, both in this and other countries, it was the exception and not the rule to have steel tyres; and a very considerable reduction in cost must take place before steel tyres could be generally introduced. There seemed some reason to anticipate such a reduction in the course of a few years' time, as far as could be inferred from the case of the Bessemer steel rails, the cost of which had originally been as much as £18 per ton, but was now reduced to only £12 per ton. The actual mileage of the steel tyres in comparison with iron tyres was another point upon which the general adoption of the steel tyres would depend, and this required to be very thoroughly ascertained. He suggested that the adoption of steel tyres for carriages and wagons would be very materially accelerated if it were possible to combine a steel face with a scrap-iron back in the tyres, whereby the cost would be greatly reduced below the present amount of £35 per ton for steel tyres, and would more nearly approximate to the cost of £22 per ton for best iron tyres.

Mr. Ramsbottom replied that he had great reason to be satisfied with the results thus far obtained from the adoption of the Bessemer steel tyres for locomotive engines and tenders; he had become convinced previously that this material was the right one and completely safe for such purposes, having himself tested it in a variety of ways, both for axles, piston rods, and other purposes; and he had therefore felt no hesitation in recommending that the necessary plant should be put down for producing the Bessemer steel and manufacturing the tyres, having satisfied himself that a saving would be effected by the use of the steel tyres, and that it would be so far advantageous to manufacture them at the locomotive works at Crewe.

In the production of the metal in the converting vessel, he had followed Mr. Bessemer's instructions very closely; but in the subsequent treatment of the bloom he had departed from the beaten track by introducing the horizontal duplex hammer, together with the other special modes of roughing down the tyres into shape before rolling, which had been described in the paper and seen by the Members on the previous day, whereby the amount of labour expended upon the manufacture of the tyres was much reduced, while the work put into them was largely increased by the great amount of effective hammering that the bloom underwent. For the suggestion of the fireclay plug in the centre of the bottom of the casting mould he was indebted to his assistant, Mr. Webb; this was found very advantageous, and he thought the same plan might be adopted with advantage in other moulds, particularly where the melted metal had to fall from some height upon the bottom of the mould, so as to allow of that part of the bottom being readily renewed when it became worn. In reference to the hammering on the beck anvil, an improvement was now being made which he expected would supersede the beck hammer altogether, and reduce the time of that part of the process from about fifteen minutes as at present to probably not more than about two minutes; the whole operation being performed by a machine which he had designed for the purpose. The present method of hammering on the beck iron had first been brought under his notice by Mr. Allen of the Bessemer

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doubt that the new tyres would last for a very much longer mileage than the best Yorkshire tyres, and if not actually equal to Krupp's tyres would certainly approach them very nearly in durability. He had not used any tyres made with a scrap-iron back and steel wearing face, such as had been suggested, and had not yet applied the steel tyres to carriages and wagons, as the whole productive powers of the works had hitherto been fully occupied with the manufacture of locomotive tyres alone; but it was intended ultimately to carry out the same system for supplying the whole of the rolling stock with the steel tyres. For securing the tyre to the wheel a number of modes had been tried, and he had now five different methods in operation, which were being watched in order to determine the best plan; and his present opinion was that the ordinary attachment by means of rivets through the tread of the tyre would be found to outlast all the others.

The great object which he had had in view in adopting the Bessemer steel for tyres and carrying out the mode of manufacture described in the paper had been to obtain tyres of a mild quality of steel, which could be thoroughly relied upon for safety in running, as he considered it was of primary importance to look very closely to the question of safety for working in the manufacture of every portion of railway rolling stock. A practical proof of the safety of the Bessemer steel tyres was furnished by the tyre exhibited to the Members at Crewe on the previous afternoon, which had required the very severe treatment described in the paper in order to break it. Another of the tyres had been even more severely tested, and the value of the test would be readily understood by all in the habit of working steel. This tyre was a defective one, which had been made in one of the earlier experiments on the manufacture of the steel tyres, and it was very much cracked about the flange. It was first tested at a dull red heat upon the ordinary tyre-blocking press by hydraulic pressure; and this failing to produce any perceptible stretching, it was subsequently heated to a bright red heat and dropped tight upon a cast-iron block, and then suddenly quenched with cold water to make it shrink violently; but even by this treatment the tyre was not broken, though it was stretched about

$\frac{3}{4}$ inch in circumference. From these results he was confident that the Bessemer steel tyres of this mild quality were much better and safer than the best description of welded iron tyres; and quite as safe as weldless tyres of any description, whether iron or steel, irrespective of the mode of fastening the tyre on the wheel. The aim in adopting the Bessemer tyres had not been so much to obtain the highest scientific results, as the best commercial results, making safety in running the first consideration and keeping also in view the question of practical economy; and it was quite possible consequently that the material which was found so suitable for the tyres might not be so well adapted for other first-class engineering purposes as the best crucible cast steel.

Mr. F. J. BRAMWELL remarked that the test which had been mentioned, of heating one of the steel tyres and shrinking it on a cold solid block of cast iron, would be fully appreciated as a most satisfactory demonstration of the thorough safety under all circumstances of tyres made of that material in the manner described in the paper.

Mr. W. FAIRBAIRN enquired what had been the experience in the manufacture of the Bessemer steel tyres as to the uniformity in the quality of the material from which they were made. The difficulty attending the Bessemer process was not the actual production of the steel, but its production with sufficient uniformity of character, [redacted]

thought it could now be fairly met by the results of experience. In dealing with iron there was a wide range of quality, and almost as great a range was found in steel. But comparing the Bessemer steel with crucible steel, the former was liable to a less extent of variation in quality than the latter, while the gradations of quality were as clearly discernible; and therefore at least as near an approach could be made to uniformity in the quality of the Bessemer steel as in crucible steel. He had indeed met with tyres made of crucible steel which had proved so hard that it had been almost impossible to turn them; but in his opinion this was much less likely to happen with the Bessemer steel. In the case of iron plates for boilers and other purposes, uniformity of strength might easily be ensured by rolling the plates rather larger than was required, and having a piece cut off each separate plate and tested; but for many purposes, such as girders, he thought plates of Bessemer steel would be safer and stronger than iron plates, on account of the soft and tough quality of the material. In connection with this point too little attention he thought was paid to the change of form occurring under strain, as a criterion of the practical value of any material, and to the amount of work that must be expended in producing this change of form before fracture could be effected. An illustration was afforded by the fact that a steel bar 12 inches long and requiring a tensile strain of 15 tons per square inch to break it might be elongated only $\frac{1}{4}$ inch before breaking, whilst an iron bar of the same length and requiring only half the tensile strain per square inch to break it might undergo three or four times as much elongation before breaking; and in like manner, to burst a bottle of lead by hydraulic power would require more work to be expended in pumping than to burst a glass bottle of the same dimensions; and the case was similar in regard to strains of compression. Thus a material which was the weaker in respect of its ultimate breaking strain might in one sense be the stronger; and hence the value ot toughness in the material employed for such purposes as girders and boiler plates.

The PRESIDENT moved a vote of thanks, which was passed, to Mr. Ramsbottom for his paper, and for the excellent opportunity afforded to the Members on the previous afternoon of witnessing the whole process of the manufacture of the steel tyres at the Crewe works.

The following paper was then read:—

ON MACHINERY FOR THE PREPARING AND SPINNING OF COTTON.

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The object of the present paper is to trace the principal mechanical steps by which the application of machinery to Cotton Spinning has been developed, and which have led to the completion of the present elaborate machines, so remarkable for the perfection of the results produced by them. The modern machines are in fact formed of a combination of numerous highly ingenious contrivances, which have been successively designed to meet the special difficulties of dealing by machinery with so delicate and irregular a material as the raw cotton fibre.

The process of spinning involves three essential and distinct operations:—

First, *Drawing*,—in which the fibres of the raw material are drawn out longitudinally, so as to lay them all parallel with one another and overlapping at the ends; as is done by the fingers of the hand spinner for forming a continuous sliver out of the short fibres lying irregularly in the bundle that is tied upon the distaff.

Second, *Twisting*,—in which the sliver previously formed is twisted into a roving or thread, for giving it longitudinal tenacity by increasing the lateral friction between the fibres; as is done by the hand spinner by twirling the bobbin on which the portion of thread already twisted has been wound.

Third, *Winding*,—in which each portion of the thread, after it has been sufficiently twisted, is wound upon the bobbin.

In the application of machinery to the performance of these operations, the great difficulties experienced have arisen from the irregular character of the cotton fibre on the one hand, and on the other from the unyielding action of machinery, which has to take

the place of the delicate feeling of the fingers in hand spinning, whereby the spinner is enabled to accommodate the action continually to the variations in the material. It is a point of special mechanical interest however to note at how early a period in the application of machinery correct ideas were developed as to the principles of action in the important successive steps: so correct indeed that they have remained unaltered in principle to the present time, although many highly ingenious improvements in detail have subsequently been effected.

It appears that the credit of the first invention of the Spinning Machine is due to Lewis Paul in 1738, little more than a century ago, all spinning having been previously done by hand. In his first machine the raw cotton was passed through a succession of pairs of rollers, each pair running faster than the preceding, so as to draw out the sliver of cotton longitudinally to any degree of fineness required. The machine thus accomplished only the drawing process, leaving the sliver so formed to be twisted and wound afterwards by hand. The great feature of this invention was that the important principle of drawing by rollers running at different speeds was thus established at the outset, to supersede drawing by the fingers in hand spinning; and this mode of drawing has been adhered to ever since as the fundamental principle in the preparation of fibrous [redacted]

In 1758 Paul further improved his original machine by rendering it capable of performing the two other processes of twisting and winding requisite to complete the operation of spinning by machinery; and he constructed a spinning machine having a circular frame containing fifty spindles. The cotton was drawn by rollers, as in his previous machine, and the sliver was delivered from the rollers to a bobbin upon each spindle, by means of an arm or flier fixed upon the spindle; and the spindle being so contrived as to go faster than the bobbin, the sliver was thus twisted into thread by the flier, before being wound upon the bobbin.

Although the two mechanical principles which have formed the basis of all subsequent spinning machinery—namely the drawing rollers running at different speeds and the differential motion of the flier and bobbin—were thus originated by Paul, it does not appear that his machines were ever practically successful; and Arkwright's spinning machine in 1769, shown in Fig. 1, Plate 68, appears to have the merit of being the first that was brought into successful operation. This machine cannot be called more than an improvement in detail upon Paul's, as the principles of the two were the same; and it is difficult to imagine that Arkwright had not seen Paul's machine. The success of the later machine may be attributed to its superiority both in workmanship and in the material employed, the earlier machine having been composed almost entirely of wood.

The four pairs of drawing rollers A A, Fig. 1, were made of brass and steel, and geared together by pinions; the bottom rollers were covered with wood and fluted, and the top ones were covered with leather, and pressed down upon the bottom rollers by the weighted cords and pulleys B B. The sliver delivered by the rollers was then twisted into a yarn or roving by the flier C, and wound upon the bobbin D. The differential motion of the flier and bobbin, by which the two operations of twisting and winding were effected, was exactly the same that is still employed for the same purpose, only the motion was obtained by different means. If the flier and bobbin both revolved at the same rate and in the same direction, no winding would take place, and the effect would be confined to twisting the sliver into a roving. On the other hand if only the

flier revolved and the bobbin were stationary, all the motion would wind and also twist, but only a single twist would be put into the sliver for each coil wound on the bobbin. But if the bobbin rotates slower than the flier, the winding is effected at just so much slower rate than the twisting as the two speeds are made to approximate. This was accomplished in Arkwright's machine by the simple means of a friction break upon the bobbin D, the bobbin being loose upon the spindle and dragged round by the thread, whilst the flier C was fast upon the spindle and driven direct by the driving strap E below. The friction break to retard the bobbin was made by a worsted cord passed round a groove in the whirl F at the bottom of the bobbin, and tightened by hand to the required adjustment by a screw pin securing the end of the cord. The drag put upon the bobbin by this friction break also put a stretch upon the roving, and caused it to be wound tight on the bobbin in solid layers instead of in loose coils. In the arm of the flier C were fixed a number of hooks, under which the roving was passed; and the winding on the bobbin was done in successive steps, by stopping the bobbin and shifting the roving successively from one hook to the next on the flier, as no idea had yet been originated of giving the bobbin a vertical motion upon its spindle so as to guide the roving on regularly in winding.

In 1770 Hargreaves invented the Spinning Jenny, shown in Fig. 2, Plate 68, the principle of which is identical with that of the present spinning machinery. It thus presents a remarkable instance of a correct perception respecting the best mode of working having been attained at so early a stage in the application of machinery to a new purpose. The operation of spinning into threads the rovings produced by the machines already described, or by the modern improved machines similar in principle, comprises the two processes of twisting and elongating the roving to form it into a thread, and then winding the spun thread into the form of a "cop" upon the same spindle by which the spinning or twisting has been performed. These two processes still continue to be effected in essentially the same manner as in Hargreaves' spinning jenny.

The twisting of the thread is effected by causing the spindles G, Fig. 2, to revolve, as though for winding up the thread, but allowing the thread to slip off the free end of the spindle once in each revolution. For this purpose the thread is led off from the top end of the spindle at an angle so much greater than a right angle that its tendency to wind in a spiral brings it to the top extremity of the spindle in each revolution, causing it to slip off the end of the spindle at each successive revolution; and the top of the spindle is shaped conical to facilitate the slipping of the thread off the end. The result is that the thread is twisted one turn by each revolution of the spindle, without disturbing or interfering with the portion of spun thread already wound up into a cop on the lower part of the spindle. The crossbar J, carrying the guiding eyes through which the several threads pass, rests at each end on a carriage that runs along the side framing of the machine; and before the commencement of the spinning by the spindles G, the crossbar is first drawn backwards from the spindles by hand through about one third the length of the machine, drawing off a continuous supply of roving from the bobbins K below, which are free to turn on their bearings. The clasp H is then pressed down tight upon the crossbar J, holding the rovings fast, and the spindles G are set in motion, twisting the lengths of thread between the spindles and the crossbar; and during the twisting the crossbar is gradually drawn backwards by hand to the end of the machine, thus producing the required elongation of the threads by tension during the spinning, as is done in the case of hand spinning by the weight of the bobbin or spindle hanging from the twisting thread. The spindles G receive their motion from the drum M driven by the driving pulley L, which is turned with the right hand by the handle N, while the left hand draws back the crossbar J by means of the handle upon the clasp H.

When the crossbar J has been drawn back to the extreme end of the machine and the spinning of the threads has been completed, they are then wound up on the spindles by depressing them all simultaneously to the lower portion of the spindles by means of the "faller wire" O, which is brought down upon the threads by the rotation of the discs P P in the direction of the arrow. The rotation

of the discs is effected by tightening the cord R which runs along the side of the machine, and they are turned back again by a counter-balance weight for raising the faller wire when the cord is released; the cord passes round three horizontal pulleys on the top of the carriage S, and is tightened for depressing the faller wire by a transverse sliding movement being given to the middle pulley by means of a hand lever, which is worked by the left hand whilst holding the clasp on the crossbar J. The threads being depressed by the faller wire, the further rotation of the spindles now causes the threads to be wound up in cops upon the spindles, the sliding crossbar J being pushed forwards gradually by hand as the winding proceeds, until it again reaches the spindles, when it is ready for beginning the spinning of a fresh length of rovings. During the winding of the threads already spun between the spindles and the crossbar J, this length of the threads is secured and separated from the untwisted rovings beyond the crossbar by the pressure of the clasp H, which is kept pressed down tight upon the threads.

On the completion of the spinning however of each length of the threads, and before the change can take place from spinning to winding, it is necessary first to unwind the short spiral of thread extending up from the top of the cop previously wound to the top extremity of the spindle. This spiral is unavoidably formed at the commencement of the twisting, before the thread can reach the [redacted]

This backing-off motion and the faller wire are identical with those now in use in the modern spinning machines, the only difference being that they are now made self-acting. In winding the cop each successive layer of thread is so regulated that a conical form is given to each end of the finished cop, in order to prevent the thread from getting loosened upon it at the ends in subsequent handling; while at the same time the crossing of the thread in the alternate spiral layers gives firmness to the cop, and still allows the thread to be afterwards drawn off it, when required for use, either by slipping off the end as in a shuttle, or by unwinding the cop on a spindle. In the spinning jenny this shape of cop was obtained by regulating the winding of the thread by means of the cord R acting upon the discs P P, raising and lowering the faller wire O during the winding so as to guide the thread upon the spindle as required for producing the desired shape of cop. The same shape of cop and mode of guiding the thread on are still adhered to in the present spinning machines; but the whole of the movements are now effected entirely by self-acting machinery.

Further improvements in the preparatory processes of carding and roving were introduced by Arkwright in 1775, which may be said to include the principal features contained in the carding and roving machines now used. The cotton delivered from the preliminary machine was formed into a roll or lap, for supplying a continuous fleece of cotton to the carding cylinders, the carding operation being repeated until the irregular mass of fibres in the raw material had been combed straight and laid parallel in the fleece of cotton with a sufficient degree of uniformity to allow of proceeding to the subsequent operations. Comb-plates worked backwards and forwards by cranks were also added for combing off the cotton in a continuous fleece from the "doffer" or taking-off cylinder of each of the carding machines. The sliver delivered from the last carding process was passed between a pair of rollers for the purpose of consolidating it by the pressure of the rollers after the loosening action of the doffing comb-plate; and it was then coiled down into a can.

The doubling and drawing process employed at this stage of the manufacture was also introduced by Arkwright at the same time, the object being to intermingle the fibres more completely in the sliver and thereby render it more uniform in quality, ready for twisting into a roving. For this purpose two or generally more of the slivers from the carding engine are passed side by side through a series of pairs of drawing rollers, each pair in succession being made to run faster than the preceding; and the last pair of rollers runs as many times faster than the first pair as there are slivers doubled together, so that the single combined sliver delivered from the rollers is drawn down to the same size or weight per foot as one of the original slivers. The doubling and drawing operation is usually repeated three times, and the ultimate sliver so prepared is then ready for the roving frame, in which it is again drawn and twisted and wound upon a bobbin.

In the roving frame Arkwright now effected an important advance upon his previous machine, shown in Fig. 1, by introducing the new principle which has since been adhered to, of driving the bobbin and the spindle independently by separate motions, instead of letting the bobbin be simply dragged round by the thread as previously described. At the same time he also introduced the conical regulating drum, for reducing the speed of the bobbin in proportion as its diameter was increased by the thickness of the coils [redacted]

eye for delivering the roving upon the bobbin, instead of the succession of hooks fixed on the arm of the flier in the previous machine, Fig. 1, for winding the roving on in a succession of steps; and a sufficient space is also left in the drawing for allowing the required amount of vertical movement of the bobbin. The invention of this principle of lifting and lowering the bobbin upon the spindle during the winding, which is employed in all the present machines, has not been traced by the writer to any earlier date than these final improvements introduced by Arkwright in 1775.

By thus making special machines for each process in the preparation of the material for spinning, Arkwright effected a most important division of labour; and the factory system, already introduced in the silk manufacture, became rapidly extended in consequence.

In the preparation of cotton the improvements introduced from time to time in each particular section of the machinery employed have been so numerous and so varied that only a slight reference can be made to them in this paper under their respective heads, in the hope that they may be made the subjects of special papers by some of the Members at future meetings.

Opening.—The first process in the preparation of the raw cotton was known as "willowing," and took its name from the willow switches formerly used for beating or opening the tufts of cotton by hand. A number of small parallel cords were stretched tight and close together on a horizontal frame, so as to form a sort of table, upon which the cotton to be opened was laid; and the cotton being then beaten with switches made of willow rods kept smooth for the purpose, the fibres of the cotton remained on the cords, whilst the sand and seeds fell through between. Some of the best descriptions of sea-island cotton are still batted in this way, for the finest counts of yarn. Several attempts were made to work the willow beaters by machinery, but they have all been superseded by opening and scutching machines on the modern principle, having revolving cylinders to act as beaters. The most primitive of these is known

as the Oldham Willow, and has a revolving cylinder about 36 inches diameter, set with spikes placed in parallel rows, and revolving against a grid of bars set with similar spikes: the cotton is fed upon the grid and beaten for a longer or shorter time according to its condition, and an exhausting fan is employed for taking away the sand and bits of dried leaves beaten out. This machine is now used only for separating hard lumps of cotton in bales packed too tightly, and for cleaning cotton waste and the refuse cast out by other cleaning machines.

Fig. 3, Plate 69, shows a section of the Cotton Opener in use at the present time for the purpose of opening out the fibres of the cotton after it has been pressed in the bales, and for extracting the sand, dried leaves, and other impurities imported with it, the object being to do this without entangling or injuring the fibre. The crude cotton from the bales is spread by hand upon the endless travelling lattice A, which conveys it underneath the iron guide-roller B with longitudinal ribs on its surface to the pair of fluted feed-rollers C. These are pressed together by the weighted lever D, and deliver the cotton to the picker cylinder E set with twelve rows of teeth, which are spaced so that the teeth follow one another spirally round the cylinder, as shown in the plan, Fig. 4. The tufts of cotton being gripped tight between the rollers C are caught by the tips of the teeth on the cylinder revolving in the direction of [redacted]

loosened by the beaters, drop out and fall through the grid J into the dust box. The cotton then passes between the two wire-gauze cylinders K, which serve as fine sieves, the interior of the cylinders being exhausted by the fan L; by this means the more minute particles of dust remaining in the cotton are sifted out, and discharged by the fan through the aperture M, thereby keeping the rooms where the machines are at work perfectly free from dust. There is thus a continual deposit of impurities taking place throughout the whole passage of the cotton through the machine, from the feed rollers C to the wire cylinders K. In the drawing only two beater cylinders E and H are shown; but the machines are more generally made with four cylinders, for cleansing the cotton more effectually, the two additional beaters being provided with four rows of teeth, the same as the second cylinder H. From the wire cylinders the loose cotton is collected again and consolidated into a fleece by the fluted stripping rollers I, running close to the cylinders K but not touching; and these deliver it to the travelling lattice N, which discharges it ready to be taken to the next process of scutching, a lap machine being sometimes attached so as to form the fleece into a lap or roll for supplying the scutcher. The beater cylinders E and H run at about 1000 revolutions per minute; the feeding lattice A travels at 6 feet per minute, which is also the surface speed of the feed rollers C; and the surface speed of the wire cylinders K, the stripping rollers I, and the delivery lattice N is 60 feet per minute.

Scutching.—The Scutching Machine now in use for further beating and cleansing the cotton delivered from the opener is shown in Fig. 5, Plate 70, having also combined with it the Lap Machine for forming the fleece of cotton delivered from the scutcher into a roll or lap. The cotton from the opener is supplied to the scutcher upon the travelling feeding lattice A, and in order to produce a uniform fleece for the further processes it is necessary at this stage to regulate the quantity fed into the scutcher, which is effected in two ways. In feeding by hand the tedious method of weighing the cotton supplied has to be resorted to, so as to distribute a uniform weight of cotton

over each foot of length of the feeding lattice, which together with the feed rollers C is driven at a uniform speed. But in the improved mode of feeding by laps B, supplied from a lap machine in connection with the opener, the top feed roller is allowed to rise and fall according to the variations in the thickness of cotton fed in, and the amount of its vertical movement multiplied by means of levers is employed to regulate by a self-acting arrangement the speed at which the feeding lattice and rollers are driven. By this means an almost uniform supply of cotton is fed to the beater H, which is composed of three plain bars, as shown in the plan, Fig. 6, and is driven at about 1250 revolutions per minute. The cotton is beaten as before against the circular grid F and perforated plate G, and the current of air from the beater wafts it forwards over the straight grid J to the wire cylinders K exhausted by the fan L, the action being exactly the same as in the opening machine. The rollers I which strip the dust cylinders deliver the fleece to a set of four callender rollers O placed over one another, so that the cotton in passing through them receives three compressions, which consolidate it into a kind of felt; the surfaces of the callender rollers are kept clean by rubbers of iron covered with flannel, which are pressed in contact with them.

The Lap Machine, for coiling the fleece into a roll or lap, has two fluted driving rollers P P running in the same direction, as [redacted]

lifted clear by the handwheel on the shaft T, so as to allow the finished lap to be removed. The driving pinion V, from which the callender rollers O receive their motion, is held up in gear by the lever W supported by a catch; and when the lap is finished this catch is released by a tappet upon the pinion X, which is driven from the bottom callender roller, the speed of the pinion being so reduced that one revolution of it corresponds to the size of lap required to be made. The catch being released allows the driving pinion V to fall out of gear, whereby the callender rollers O are stopped; and the lap rollers P continuing to revolve break off the fleece, ready for removing the finished lap from the machine. By changing the pinion X carrying the tappet, the size of lap made by the machine can be varied as desired.

The scutcher shown in Fig. 5 is a single machine, and it is usual to pass the cotton first through a double scutcher of similar construction, but having a second set of feed rollers with beater and wire cylinders, running at a higher speed; the second pair of wire cylinders and stripping rollers are driven three times as fast as the first pair, so that they deliver a fleece of one third the thickness first supplied to the machine. Three of the laps from this double scutcher are then fed into the single scutcher shown in the drawing, as at B B B, Fig. 5, being spread upon the surface of the feeding lattice A in three layers on the top of one another, so as to present to the feed rollers a uniform fleece equal in thickness to that fed into the first scutcher. By thus doubling the laps the fibres are more thoroughly mixed, and the fleece is thereby made more uniform in thickness.

Scutching machines having a revolving beater, composed of two plain bars describing a circle of about 14 inches diameter, were introduced about 1810; and these machines contained also a travelling feed lattice, two pairs of feed rollers, and a second travelling lattice for conveying the beaten cotton underneath a perforated revolving cylinder, the interior of which was exhausted by a fan. The cotton passing through this machine was delivered in a loose fleece, and a few years later a lap machine was added for coiling the fleece into a lap. Other improvements have gradually

been introduced up to the present time, as regards both design and workmanship: the cylinders and beaters have been put in perfect balance, so as to revolve steadily at the high speed required, and the forms of teeth on the cylinders have been arranged for greater strength and greater facility of construction; stronger and simpler gearing has been employed, improvements have been made in the form and construction of the bearings of the beaters and other quick revolving shafts, so as to ensure more efficient lubrication, and air-tight dust boxes have been added with moveable doors for facility of cleaning; and the self-acting arrangements have been introduced for stopping the machine when a given length of fleece has been delivered, and for regulating the rate of feed according to the thickness of the cotton supplied, so as to dispense with the previous plan of weighing the cotton in feeding. Thus by successive improvements through a long series of years the difficulties which originally presented themselves in the successful adaptation of machinery to cotton cleaning have been overcome; the cotton can now be perfectly cleaned without injury to the fibres, and the laps are produced uniform in length, breadth, and thickness of fleece, and so thoroughly felted that they uncoil at the carding engine in the next process without any derangement of the felted fleece.

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further carding; and the lap formed of this new fleece is then fed into a second or "finisher" carding engine. As many as 96 slivers from the breaker card, each drawn out of a separate can, are laid together by the doubling machine into a single fleece for the supply of the finisher, in order that the mixing of the cotton may be more thoroughly effected, and more perfect uniformity ensured in the sliver delivered by the finisher. For the finest qualities of yarn the finisher card is itself used as a breaker, and the sliver delivered by it is afterwards combed by a combing machine.

The Roller and Clearer Carding Machine employed at the present time as a breaker card for performing the first carding of the fleece is shown in section in Fig. 7, Plate 71; and consists of a main carding cylinder A, round which are arranged a series of pairs of carding rollers or "workers" B B and clearing rollers or "strippers" C C. The surfaces of all these are covered with cards, and they are made to revolve so close together as to allow the tips of the card teeth just to clear one another. The cards are a kind of wire brush with inclined teeth, as shown full size in Fig. 9, and are made of staples D of fine steel or iron wire, each about 3-8ths inch long and 3-16ths inch wide, with a side bend in the middle of their length. These are fixed close together into a strip of webbing about $1\frac{1}{2}$ inch wide, which is wound tight round the cylindrical rollers in a continuous spiral, keeping the staples pressed home in the cloth by the surface of the cylinder, so that they have an elastic firmness which keeps their points up to the work.

The working width of the machine is about 40 inches on the card teeth, corresponding with the breadth of the fleece in the lap E by which the carding engine is fed. The unlapping of the fleece is performed by the rollers F on which the lap rests, and the fleece is then drawn forwards under the feed roller G, and delivered to the taker-in roller H revolving in the direction of the arrow. At this point the carding or combing action commences, the fleece being held by the feed roller G travelling at the slow speed of only about $\frac{3}{4}$ foot of surface per minute, while the taker-in H runs much faster, at about 800 feet per minute surface speed; and the carding teeth on the taker-in being bent forwards in the direction

of motion, the points of the teeth strike down into the fleece held by the feed roller, and comb out the fibres, while the impurities separated fall to the ground. The fibrous tufts of cotton are carried round on the underside of the taker-in to the main carding cylinder A, which revolves in the same surface direction with a speed of about 1600 feet per minute. The teeth of the carding cylinder being bent forwards in the direction of motion sweep off the cotton from the taker-in teeth inclined in the same direction but running at only half the speed, and carry it forwards to the dirt roller J, the teeth of which face those of the carding cylinder, and travel with a very slow motion of only about 16 feet per minute. The dirt roller thus assists in combing out the fibres, and holds in the interstices of its wires any impurities that it receives from the cotton, which are carried forwards and stripped from it by a vibrating comb, so that they accumulate in a roll on the upper surface of the dirt roller, to be taken away by hand at intervals.

The carding cylinder then carries the cotton forwards to the several pairs of workers and strippers, one of which is shown to a larger scale in Fig. 8; and at each pair in succession the fibres undergo a further combing out and straightening. The motion of the teeth of all these pairs of rollers is in the same direction as that of the adjacent teeth on the main carding cylinder, as shown by the arrows in Fig. 8, but at a much slower speed; and the teeth of the strippers C are inclined forwards in the direction of

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the teeth of the stripper therefore sweep off the cotton from the worker, and are themselves stripped in the same way by the carding cylinder running at the higher speed. After passing the six pairs of workers and strippers, the fleece of straightened fibres is taken off in a continuous sheet from the carding cylinder A by the doffer K, the teeth of which face those of the cylinder and move in the same direction but at a much slower speed of only about 65 feet per minute; the fleece thus receives a further straightening and stretching in quitting the carding cylinder, and is carried round on the underside of the doffer to the vibrating comb I, which describes a short arc of $1\frac{1}{4}$ inch vertical motion and is driven by balanced cranks at about 800 double vibrations per minute. This comb strips the fleece from the face of the doffer in its down stroke and clears itself in rising; and the thin fleece, of the full width of the machine, 40 inches, is then gathered in by lateral guides to a width of 6 inches, and finally into a smooth bell-mouthed round funnel L, having a hole only $\frac{1}{2}$ inch diameter, through which the contracted ribbon or sliver is drawn by the two pairs of drawing rollers M, the second pair running one half faster than the first, whence it passes to the coiler N and can O.

The coiler consists of a revolving plate N having an eccentric aperture, through which the sliver is passed from the pair of rollers P above the plate, so that it is delivered into the can in circular coils. The can O however is also made to revolve with a slow motion in the opposite direction to the coiler, and the centre line of the coiler N is eccentric to the axis of the can, whereby the sliver delivered from the coiler describes a succession of hypocycloid curves in the can, the circles of sliver being laid into the can so that the outsides of the coils touch the inside of the can. The sliver thus forms coils continually crossing one another, so that the can is filled up solid throughout, and when taken to the doubling frame the coils of sliver come out again without adhering to one another.

The Flat Carding Machine employed at the present time as a finisher card for performing the second carding operation is shown

in Fig. 10, Plate 72; and consists of a main carding cylinder A, as in the breaker card, but the pairs of workers and strippers employed in the first carding are here replaced by a series of flat cards D D, connected together by links so as to form an endless travelling lattice. The lap E, formed of a number of slivers from the breaker card laid together into a fleece by the doubling machine, is supplied to the carding cylinder A by the feed roller G and taker-in H, in the same way as in the breaker card; and the carding cylinder A is driven at the same speed of about 1600 feet of surface per minute. A single worker B, called the fancy roller, with a stripper C, is placed immediately beyond the taker-in H, running in the same direction as the adjacent surface of the carding cylinder A; but in this case the teeth of the fancy roller B are bent forwards in the direction of motion, and it therefore requires to be driven at a higher velocity than the carding cylinder, and has accordingly a surface speed of 2000 feet per minute. It thus seizes the cotton from off the teeth of the main carding cylinder A, and throws it against the teeth of the stripper C facing those of the fancy roller; and the fibres having thus been subjected to a preliminary carding are again swept off the teeth of the stripper, moving at only 400 feet per minute, by the higher speed of the main carding cylinder A.

The cotton is then carried forwards by the carding cylinder to the series of flat cards D D, Fig. 12, Plate 73, which are made of [redacted]

delivering side of each flat is closer to the cylinder, and a wider space is left at the entering side between the flat and the cylinder for the cotton to enter, as shown half full size in Fig. 15. The angle thus formed is called the bevil of the flat, and the correct adjustment of this inclination is a point of great importance and delicacy; the bevil is obtained by cutting a bevil groove Q in each end of the flat at the part where it is to rest upon the circular guide on each side of the machine, as shown enlarged in Figs. 14 and 15, where the dotted circle X X represents the edge of the guide on which the flat travels, and the dotted circle Y Y indicates the surface of the main carding cylinder A.

The endless lattice of flats D D is carried over the three shafts P P P, and on quitting the carding cylinder A each flat in turn is stripped of any fibres or impurities adhering to it by the vibrating comb R, which describes an arc of 1 inch and is driven at the rate of 40 double strokes per minute by the cam S, Fig. 13. The flats are further cleaned by the brush T, shown in plan in Fig. 11, running at a surface speed of 50 feet per minute; and they are then passed over a guide U, which holds them up against an emery wheel V running at the high speed of 550 feet per minute and traversing across the machine along the length of the flats, whereby the faces of all the cards are successively ground to a true surface whilst at work, and the points of the wires sharpened. The same mode of grinding is also employed for keeping true the surfaces of the carding cylinder and doffer. The fleece of straightened fibres is taken off in a continuous sheet from the carding cylinder by the doffer K and vibrating comb I, and is contracted into a sliver and coiled down into the can O in the same manner as previously described.

In Arkwright's improved form of the early carding engine the upper portion of the carding cylinder was covered over by a series of bars of wood called "top flats," the underside of which was covered with card teeth facing the teeth of the cylinder. These flats were stationary, held in their places by pins fixed in the framing, and were adjusted to the required bevil by two set-screws at each end; and they were lifted off and stripped of their refuse by hand cards at

intervals. The stripping by hand labour however was an unhealthy and disagreeable process; and as bad work and spoiled cotton were the consequence whenever it was not done regularly and thoroughly, many arrangements have been introduced from time to time for stripping the flats mechanically. In this direction Messrs. Buchanan of Catrine and Mr. Bodmer of Manchester led the way, although the machinery employed by them was never generally adopted. Within the last few years however a much simpler mechanism for this work has been introduced by Mr. Wellman, an American, the application of which has received a great stimulus from the difficulty of obtaining men to perform the stripping by hand; and it is now extensively used. Metal flats were introduced by Mr. Smith of Deanston, and these were linked together in the form of an endless lattice, which was made to travel slowly forwards over the carding cylinder; and each flat was adjusted to the proper bevil by two screws at each end, which travelled over two circular guides concentric with the carding cylinder. Another short flat guide at the back of the flats brought them into contact with a stripping brush, which was cleaned by a comb, and the comb teeth were scraped clear by a tin knife. These flats were used in several of the Scotch mills, but few of them were introduced into Lancashire. The flat carding machine was further improved by Mr. Evan Leigh, by cutting the bevil on the ends of the flats, as shown at Q Q, Fig. 14, and making the circular guides over [redacted]

carding cylinder in a more divided state, and more equally distributed over its surface. Carding machines are also sometimes made which are a combination of the breaker and finisher card, having rollers and clearers on the side of the cylinder next the feeder, and flats on the side next the doffer.

The practical difficulty originally experienced with the carding engine consisted in getting the cards to work sufficiently near to one another without occasionally coming in contact, which destroyed the carding points. The surfaces on which the cards were fixed were generally constructed of wood, and therefore varied with every change of the atmosphere from the shrinking or swelling of the wood, so that the faces of the cards had to be made true each time by grinding down the points of the wires at the full parts. Moreover the cylinders and rollers were not carefully constructed so as to run with a steady motion; and the fixings for carrying the different journals were not capable of a fine adjustment, nor were they steady after being set. These defects are now overcome by using iron instead of wood, and by the aid of machinery and tools adapted for making all the parts accurately; fine adjustments are provided, and the adjustable portions are made as firm when set as if fixed. These improvements cause less grinding and stripping to be required, as the finer and truer the points of the wires can be maintained, the clearer the cards continue in working; and thus the carding engines have now been brought into their present successful and extensive operation.

Drawing.—The slivers from the finisher card are next taken to the Drawing Frame, shown in section in Fig. 16, Plate 74; which contains generally four pairs of drawing rollers A, each pair running faster than the preceding, and the front pair running at six times the surface speed of the back pair. Six slivers B in separate cans from the carding engine are fed up together to the back pair of drawing rollers, being combined together by passing between two guide pins C; and after being laid together and drawn out to six times the original length, the single sliver so produced is passed through a funnel to the pair of callender rollers D, by which it is delivered to the coiler E, and

coiled down into the can F in the same manner as in the carding machines. This combined sliver having been doubled six times and drawn six times is the same weight per foot as each of the original slivers fed up to the back pair of rollers; and the object sought in the doubling and drawing process is to equalise the distribution of the cotton fibres and produce slivers of more uniform strength and texture by the combination. The process is repeated three times in this machine, and the extent of combination or intermixture obtained in the ultimate slivers is therefore represented by the cube of six or 216 times, in comparison with each of the original slivers first supplied to the machine.

In order to ensure the drawing rollers being always supplied with the full number of six slivers, each of the slivers fed up to the rollers is passed over a guide G, turning on a centre pin and nearly balanced, so as to turn with a slight pressure; and during the working of the machine this guide is depressed by the weight of the sliver into the position shown by the full lines. But in the event of the sliver breaking or running out, the tail of the guide being overweighted drops into the position shown by the dotted lines, and catches the vibrating finger J, which is worked by an eccentric on the shaft H running at 70 revolutions per minute. This shaft is driven at the end by a small crown ratchet-clutch, held in gear by a spiral spring behind and driving by the inclined faces; so that, whenever the shaft H is stopped by the tail of a [redacted]

construction of the roller supports so as to be easily set and adjusted to the different distances required to suit the different lengths of cotton fibre worked; the addition of the self-acting stop motion, for stopping the machine when any one of the slivers breaks or runs out; a simpler mode of suspending the weights from the top rollers; and the use of an endless travelling cloth over the surfaces of the top rollers, as shown in Fig. 16, for cleaning off the waste or "fly" from the rollers. The top rollers are also made with dead spindles and loose bosses, the bosses being driven by independent motions. In drawing frames used to prepare slivers for the finer counts of yarn, an additional stop apparatus is provided for stopping the machine whenever a breakage of the sliver occurs between the front pair of drawing rollers and the callender rollers D, Fig. 16, or when the can F is full or a given length of sliver has been delivered; this stop action is worked from the same shaft H as that employed for breakages of the supply slivers.

Slubbing, Intermediate, and Roving.—The slivers delivered from the drawing frame are conveyed to the Slubbing Frame, into which they are fed either single or double, passing over a guide, like that in the drawing frame, to a set of three pairs of drawing rollers; the last pair runs at five times the speed of the first, so that the sliver is again increased in length five times in passing through the rollers. From the drawing rollers the sliver, now called "slubbing," passes to a revolving flier carried upon a vertical spindle, by which it is twisted and then wound upon a bobbin revolving loose upon the same spindle. The flier runs at a constant speed, while the bobbin is driven by means of a differential motion at a speed varying according to its increasing diameter as the slubbing is wound on; and the lifting movement, for raising and lowering the bobbin upon the spindle so as to wind on the slubbing in regular coils, is also worked by the same differential motion. The speed of the flier is 500 revolutions per minute, and the slubbing is delivered from the drawing rollers at the rate of 50 feet per minute, so that the number of twists put into it in this machine is $\frac{5}{6}$ twist per inch of length.

The bobbins from the slubbing frame are next supplied in pairs to the Intermediate Frame, in which the slubbings are doubled by passing two of them together through a set of three pairs of drawing rollers, and then twisting them into one by means of a flier, and winding on a bobbin in the same manner as in the slubbing machine. In this process, "intermediate" between the slubbing and roving, the amount of drawing produced by the rollers is 5 times; and $1\frac{1}{4}$ twists are put into the doubled slubbing by the flier per inch of length delivered from the rollers.

In the Roving Frame, shown in Fig. 17, Plate 75, the contents of two bobbins A A from the intermediate frame are again doubled, drawn, and twisted as before; and the cotton, now called "roving," is wound upon bobbins ready for being finally spun into thread. The extent of drawing in the three pairs of drawing rollers B is 6 times, and the front pair runs at a surface speed of 29 feet per minute; the flier C is driven at 900 revolutions per minute, and thus puts $2\frac{1}{2}$ twists per inch into the roving. The bobbins A A supplying the cotton for the rovings are fitted upon wood spindles called "skewers," pointed at the lower end where they rest upon their bearings, which are shallow cups made of glazed earthenware; these are found very durable, lasting for twenty years before requiring renewal, but when brass or cast-iron bearings were previously tried they were found to be worn through in as many months, whilst the skewers made of lance wood were but little worn. The spindles D carrying the fliers are driven by skew-bevil wheels on the shafts E at the bottom of the machine. The bobbins F are loose upon the spindles, and are driven by skew-bevil wheels on the shafts G, carried in the bobbin-lifter H, which supports the bobbins and gives them the vertical movement on the spindles D for winding the roving in uniform coils from top to bottom of the bobbins.

As the winding is effected by the difference of speed between the bobbin and flier, both of which revolve in the same direction, the speed of the bobbin may either exceed that of the flier, or the converse; and both plans are in use in the present machines. When the bobbin runs in advance of the flier, the speed of revolution of the bobbin has to be gradually diminished as its diameter increases

by each successive layer of roving wound on; otherwise the delicate roving would be irregularly stretched or broken by the relatively increasing surface speed of the bobbin, as the speed of the drawing rollers B and the flier C is required to be constant in order that an equal amount of twist may be put into the roving throughout its entire length. On the other hand when the bobbin follows the flier, its speed of revolution has to be gradually increased as its diameter increases by winding. In either case the vertical reciprocating movement of the bobbin-lifter H has to be gradually retarded, to allow a longer time for winding each successive layer of roving upon the increasing circumference of the bobbin; and the length of the vertical motion is also diminished at each reciprocation, so as to give the required conical form to the ends of the bobbin, which is effected by means of a separate shortening motion.

The arrangement employed at the present time for obtaining the differential speed of the bobbin and bobbin-lifter in the slubbing, intermediate, and roving frames, is Houldsworth's ingenious and successful Differential Motion, which was introduced in 1826, and is shown in Fig. 18, Plate 76. It consists of three portions, the first of which is driven at a constant speed, and drives the spindles and fliers; the second is driven from the first at a speed varying in proportion to the increase of diameter of the bobbins; and the third portion, from which the bobbins and bobbin-lifter are driven, receives a differential motion compounded of the other two, and therefore also varying with the increasing diameter in winding. The shaft K being driven at a constant speed by the driving strap over the pulley L imparts a uniform speed to the spindles and fliers by the pinion M, which is fast upon the shaft. The pinion N driving the bobbins and bobbin-lifter runs loose upon the shaft, and is driven through the differential bevil gearing O by the bevil wheel P keyed upon the shaft K. The two bevil wheels O O, through which the differential motion is obtained, are centred in the disc wheel Q running loose upon the shaft K. If the disc wheel were held stationary, the pinion N would be driven through the wheels O O at the same speed as the wheel P, but in the contrary direction,

and would therefore drive the bobbins at the same speed as the spindles; but if the disc wheel Q were made to revolve upon the shaft K at half the speed of the wheel P, but in the contrary direction, the pinion N driving the bobbins would run at double the speed of the wheel P. If therefore the disc wheel Q be driven at an intermediate speed, and this speed be also made to vary in proportion to the increasing diameter of the bobbins, the pinion N will receive and impart to the bobbins and bobbin-lifter a differential speed, which also will vary in the ratio of the diameter of the bobbins. This object is obtained by driving the disc wheel Q through the pair of regulating cones R and S, which are parallel but reversed end for end in respect to each other; the first cone R is driven at a constant speed direct from the shaft K, and drives the second cone S through the strap T, which is made to travel gradually from one end of the cones to the other. Hence the disc wheel Q, which is driven by the second cone S, runs at a varying speed depending upon the position of the strap upon the cones; and by making the strap travel along the cones at a rate corresponding with the increasing diameter of the bobbins, the speed of revolution of the bobbins is accurately proportioned to their diameter so as to give the required uniformity in surface speed throughout the winding. The travel of the strap T is effected by a rack motion I and ratchet-wheel J, Fig. 17, each vertical reciprocation of the [redacted]

8 revolutions for every 6 of the flier-pinion M. Similarly when the strap is at the end V of the cones, the ratio of speed of the disc wheel to the driving shaft K is $\frac{1}{2} \times \frac{3\cdot5}{6\cdot0} \times \frac{1}{5} = \frac{1}{16}$ nearly; that is the disc wheel makes one revolution for every sixteen of the driving shaft, and in the contrary direction; and therefore the bobbin-pinion N makes 18 revolutions for every 16 of the flier-pinion M. Hence the ratio of speed of the bobbin-pinion to the flier-pinion is 32 to 24 in the first case and 27 to 24 in the second; and the total reduction of speed of the bobbins, whilst the strap travels along the entire 30 inches length of the cones, is 5-32nds or 16 per cent. of their original speed, which is the range of variation required to allow for the increasing diameter of the bobbins in winding.

The differential motion affords the means of obtaining this delicacy of adjustment with a compact and easily worked apparatus; and by virtually magnifying the range of variation required avoids the use of cones with too small a taper for good working. The arrangement shown in Fig. 18 is for the case of the bobbin running in advance of the flier, when the speed of the bobbin has to be reduced as its diameter increases in winding; and the action of the differential motion is exactly similar in the converse case of the bobbin following the flier, the only difference being that the disc wheel Q must then be made to rotate in the same direction as the driving shaft K, instead of in the contrary direction. As the advance of the driving strap T along the cones is a uniform amount at each reciprocation of the bobbin-lifter, the driving cone R requires to be shaped with a concave outline and the driven cone S with a corresponding convex outline; since the absolute increase made in the diameter of the bobbin by each successive layer of roving bears a continually diminishing ratio to the increasing diameter of the bobbin, requiring the variation of speed therefore to be effected also in a continually diminishing ratio.

Arkwright's Can Frame was the first machine invented of the class now comprising the slubbing, intermediate, and roving frames above described; it consisted of a row of revolving cans, into which the sliver was delivered from a set of drawing rollers similar to those used in the drawing frame. The cans were driven by bands

passing round pulleys at the bottom, and the top of each can was contracted into a tubular neck, forming a bearing, which ran in a bush in the framing of the machine, and through which the sliver from the drawing rollers was delivered into the can in irregular coils. There were three or four pairs of drawing rollers in this can frame, and two of the slivers from the drawing frame being fed into the rollers were doubled and drawn into one of about eight times the original length, which was delivered into the can; and when the can was full the sliver or roving was taken out, and wound upon bobbins by a separate winding machine. As the sliver was merely delivered into the can of the can-frame through the central orifice at the top, it did not receive any regular coiling into the can, and the amount of twist imparted to it was therefore irregular; the can made about 100 revolutions per minute, and the sliver being delivered from the rollers at about 16 feet per minute, the average twist amounted to only about ½ turn per inch of roving. Hence the delicate roving was liable to be injured in being conveyed to the winding machine.

The next step in improvement was made by substituting spindles, fliers, and bobbins, in place of the cans in the can-frame; and the spindles and fliers being driven at a constant speed, the differential motion was applied for driving the bobbins and bobbin-lifter at the varying speed required by the increasing diameter of the bobbins.

[redacted]

is much more convenient than having to change the rack. When this form of the differential motion was first applied, one cone drum only was used, with counter pulleys, and a weighted pulley for keeping the strap tight; but latterly the two cone drums shown in Fig. 18 have been used instead, made with corresponding concave and convex surfaces so that the strap continues equally tight in all positions.

Spinning.—The final operation of spinning into threads the rovings delivered from the roving frame has been the subject of so great an exercise of inventive abilities, and has undergone so many practical improvements in detail down to the present time, that it is impossible to do more in the present paper than notice briefly the more important steps which have led to the remarkable perfection attained in the self-acting mules now employed for this purpose.

In the practical working of Arkwright's spinning machine and Hargreaves' spinning jenny, Figs. 1 and 2, Plate 68, it was found that the rovings and threads produced were both coarse and uneven, only fit for the manufacture of quiltings, and poorly adapted even for that purpose. A great improvement in this respect was effected in 1779 by Samuel Crompton's spinning machine or "mule," which was a combination of Paul's or Arkwright's spinning machine and Hargreaves' jenny, combining the drawing roller arrangement in the former with a modification of the sliding crossbar and spinning spindles in the latter. In this machine the spindles were placed in a moveable carriage, which had a stretch or run of about 54 inches; and the rovings delivered from the drawing rollers in a soft state were further drawn by the spinner in pulling the carriage backwards from the rollers, and completely twisted by the receding spindles, ready for being wound upon the spindles during the run-in or return traverse of the carriage and spindles. In the spinning jenny each successive length of the rovings was held by the clasp on the sliding crossbar, and the stretching of the rovings was done entirely by drawing back the crossbar by hand from the spindles; and in Arkwright's machine

the stretching was performed entirely by the rollers: but in Crompton's mule the stretching was accomplished partially by the drawing rollers, when the carriage and spindles began to recede from the roller beam, and partially by the continued run-out of the carriage after the rollers had been stopped. The rollers were stopped when the carriage had receded nearly the length of its run, and they then acted as a clasp to hold the threads during the completion of the stretching and twisting.

Crompton's first mule contained about thirty spindles; and the threads spun by it were far superior in regularity, strength, and fineness, to any ever spun before. They realised about double the prices obtained in 1743 for the same counts of yarn spun by other machines, and must therefore have been very superior in quality, having been produced much more cheaply; and in order to show what could be done with the mule, small quantities were spun as fine as No. 80, which is such a quality of thread that 80 hanks of 840 yards each weigh together 1 lb. The adoption of these mules extended so rapidly that in 1811, thirty-two years after the first was made, there were 600 mills containing 4,209,000 spindles working on this plan, and only 310,500 spindles on Arkwright's plan, and 155,900 spindles on the spinning-jenny plan.

Many of the principal movements however in the working of Crompton's mule still required to be performed by hand by the [redacted]

self-acting was therefore the great aim in the subsequent improvements.

In 1818 the entire operation of winding up the spun threads into cops on the spindles was rendered altogether self-acting by Mr. William Eaton. This involved both a self-acting method of performing the backing-off, which has to be done at the conclusion of the twisting of each stretch, before the winding begins; and also a self-acting arrangement in connection with the faller-wire, for guiding the threads regularly upon the cops during the winding, and a self-acting contrivance for regulating the speed of the spindles according to the increasing size of the cops.

The arrangement of Eaton's Backing-Off Motion is shown in Figs. 19 and 20, Plate 77. The main shaft or "rim shaft" A, from which the driving motion of the spindles in the travelling carriage is derived, is itself driven in the forward direction during the twisting, and again during the winding, by the driving strap running on the fast pulley B, as shown by the dotted lines in Fig. 20. The loose pulley C communicates a slow motion through intermediate pinions to the wheel D revolving loose upon the shaft A but in the contrary direction; and at the other end of the shaft A is a corresponding wheel E fast upon the shaft. The two toothed sectors FF are keyed upon a shaft G, which is carried in the rocking frame H; and the weight K on the rocking frame is constantly acting to draw the sectors back, out of gear with the wheels D and E; while the sectors themselves are only partly counterbalanced by the second weight L, and are ready to fall down into gear with the wheels as soon as the catch I, by which they are held up out of gear, is released. When the twisting of the threads is completed, the driving strap is shifted to the loose pulley C, and the forward motion remaining in the shaft A is arrested by a friction break carrying a ratchet wheel, which is caught by a hook falling into gear at the moment of reversing the strap. The pull upon this hook extends a spiral spring, the recoil of which is made to release the catch I; and the sectors F falling into gear with the wheels D and E, a backward motion is then communicated

to the shaft A from the loose pulley C running forwards, whereby the spindles are made to turn backwards through the few revolutions necessary for backing off the spiral coils of thread at the top of the spindles, preparatory to winding. As the form of cop employed was a simple cone, increasing in height at the same time as in diameter (as shown in Fig. 21), the length of the spiral coils that require backing off at the top of the spindles becomes less with the increasing height of the cops on the spindles, and the number of backward turns in the backing-off has therefore to be gradually diminished as the cops approach completion; this is effected by an adjustable stop underneath the sectors F, which is gradually elevated in proportion to the increasing height of the cops. This stop is connected with a lever catching against a stud at the lower extremity of the arm H of the rocking frame; and the downward movement of the sectors F, while in gear with the wheels D and E, depresses the stop until at length the arm H is liberated; the weight K then withdraws the sectors out of gear, whereby the backward motion of the shaft A is stopped. By then shifting the driving strap to the fast pulley B, the shaft A is again driven in the forward direction, and the threads previously spun are wound up on the spindles as the carriage runs inwards. The pin J fixed upon the carriage, travelling inwards in the direction of the arrow, now comes in contact with the tail of the lever M, and lifts the [redacted]

during the run-out in the opposite direction the weight B is held up in the position shown, by the catch F holding the tail of the lever G. This catch is withdrawn by the downward movement of the sectors in the backing-off motion, and the weight B then brings the front end of the lever G down upon an arm on the front side of the faller shaft C, depressing the faller wire A upon the threads H. The roller I, carried upon an arm on the back of the faller shaft, is thus brought up against the pin J fixed in the parallel-motion bar K, and is "locked" by the latch L; so that by the vertical movement of the bar K the faller wire A is raised and lowered during the winding of the threads, for guiding them upon the cops from end to end. The reciprocation of the bar K is obtained by its bottom end resting upon the shaper fusee or long tapered cam M, which is driven by the pinion N from the toothed wheel O travelling along a rack P fixed upon the floor. As soon as the carriage has begun to run in, the weight B is lifted off the faller and raised again to its original position by the tail R of the lever coming in contact with a fixed stop S. When the carriage arrives at the end of its run-in, the sliding bolt T coming against a fixed stop pushes back the latch L, and unlocks the roller I; and a balance weight upon the back of the faller shaft C raises the faller wire A clear off the threads into the extreme position shown by the dotted lines. For regulating the shape of the cop as its size increases, the shaper fusee M is gradually traversed endways along its shaft N by the rack and pinion U driven by a worm wheel from the ratchet V, which is turned round one tooth at a time by the lever W coming against a stop X fixed on the floor at each end of the run of the carriage.

In 1825 further improvements were introduced by Mr. Maurice de Jongh, the backing-off motion being driven by a rack instead of by sectors; and with the backing-off was combined the process of putting down the faller wire to the required part of the cops for the commencement of the winding. The working of the faller for guiding the threads during winding was effected by an arm on the back of the faller shaft, carrying a roller, which travelled along a template or "copping rail" extending the whole length of the

stretch. The upper edge of this copping rail was shaped according to the form of cop required, and the entire rail was gradually lowered by a regulating screw at each end as the cop was built up. The winding of the threads on the cops was done by employing a slack strap or friction strap for driving the main shaft or "rim shaft" of the mule, during the run-in of the carriage; and this strap was tightened by a weight and two friction pulleys pressing against it, the weight being adjusted so as to make the strap drive or slip as required for keeping the threads in proper tension.

It was also in 1825 that the late Mr. Richard Roberts' Self-Acting Mule was first brought out, which, with the addition of further improvements subsequently introduced by himself and others, is the form of self-acting mule almost universally employed at the present time for spinning cotton. In this mule the faller wire was for the first time put down by the agency of the "rim shaft" or main driving shaft of the machine, during the time that the shaft is turning the reverse way for backing off.

The arrangement of Faller-Wire Motion, as employed in the present spinning mules, is shown in Figs. 22 to 25, Plates 79 and 80. A is the top-faller arm, which is made of the sickle shape shown in the drawing for the purpose of enabling it to put down the faller wire to the bottom of the cops J, without the arm itself being required to pass down between the cops, so as to save room in the

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part of a revolution in the reverse direction, as indicated by the arrow, sufficiently for unwinding the coils in backing off; and the snail F then comes into action and winds up the chain D, thereby bringing the top faller-wire A down upon the threads W and depressing them towards the bottom of the cops. On the back of the faller shaft I is fixed the curved arm B, against which bears the vertical locking bar H; and when the arm B is lifted by the depression of the faller A, its extremity is caught by the recess in the bar H, which is thrown forwards by the bell-crank lever K, as shown in Fig. 24; the tail of this lever having been brought, by the run-out of the carriage G, under the corresponding bell-crank L fixed in the end frame of the mule, has previously extended the spiral spring attached to the bell-crank L, Fig. 23, the recoil of which throws the locking bar H forwards as soon as the arm B is sufficiently raised, Fig. 24. The pulley E is carried on a rocking lever R, the tail of which presses against the stop S in the end frame of the mule during the time that the chain D is depressing the faller, Fig. 23; but at the moment when the locking bar H is thrown forwards to lock the faller arm B, the stop S is lowered, as shown in Fig. 24, clear of the tail of the lever R, allowing the pulley E to yield to the further pull of the chain D until the reverse motion of the tin roller in backing off is stopped; by this means the snail F, Fig. 23, is prevented from depressing the faller wire A beyond the required distance down the height of the cop.

The faller being thus locked, the carriage G begins to run in, in the opposite direction to that indicated by the arrows in Fig. 22; and while the spindles wind up the threads on the cops, the faller wire is gradually allowed to rise by the locking bar H running down the inclined copping rail M, the curved arm B being kept constantly pressed home in the notch of the locking bar, by a counterbalance weight or spring acting on the back of the faller shaft I to raise the faller A. The length of the stretch or run-in of the carriage G is 63 inches, which is therefore the length of thread to be wound upon the cop J at each time of winding; and this whole length of 63 inches of spun thread in each stretch is wound upon the cop during each stroke of the faller wire. The mode of building up the

cop in successive stages is shown half full size in Fig. 26, Plate 81; and in order to allow for the increasing diameter of the cop, the successive layers of thread are wound upon it in more open coils as the size increases, as indicated by the dotted lines, which is effected by gradually increasing the range of the faller wire; at the same time the ends of the cop are made of the conical form shown in the drawing. The length of range or "chase" of the faller wire at the commencement of the cop upon the bare spindles is only from A to B; but this is gradually increased until the cop has attained its full diameter C C, when the length of range is from C to D; after which the range is slightly diminished again to the length E F in finishing the cop. For the purpose of obtaining the requisite motion of the faller wire for giving these successive shapes to the cop during the winding, the extremities of the copping rail M, Fig. 22, are supported on the two sliding wedges N and O, which are kept at an invariable distance apart by a connecting rod. In commencing the winding of a set of cops upon the bare spindles, as shown at A B in Fig. 26, the copping rail is set at the top of the wedges and is at its smallest inclination; and after each successive layer has been wound on, the two wedges are slided from under the rail by a traversing screw worked by a ratchet-wheel, which is advanced one or more teeth during each run-out of the carriage G, Fig. 22. By this means the copping rail M is gradually lowered at both ends, and at the same time its inclination

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the point at which the winding of the new layer is to be started, about three coils being wound on during the descent of the faller, as indicated by the spiral dotted line from F to E in Fig. 27, and the remainder during the rise of the faller. When the spindles arrive at the rollers P, as shown in Fig. 25, having wound up the 63 inches stretch of threads, the stop U pushes back the locking bar H, thereby releasing the faller A, which immediately rises clear of the threads W.

The counter-faller wire is carried by the arm V from a second shaft behind the top-faller shaft I, and during the winding it bears up constantly against the underside of the threads W, as shown in Figs. 23 and 24, with a slight pressure from a counter-balance weight or spring acting on the shaft, so as to ensure keeping the threads in proper tension; during the spinning the counter-faller is held up just beneath the threads, but without touching them, as shown in Fig. 22. The arm V of the counter-faller is curved as shown in the drawing, so as to reach over the shaft I of the top faller, and also to avoid passing down between the cops; and the curved arm B on the back of the top-faller shaft I is shaped so as to clear the shaft of the counter-faller. The height of the counter-faller wire is employed as a means of regulating the speed of the spindles in winding, in the manner afterwards explained, so as to avoid the occurrence of any slack in the threads.

Roberts' Backing-Off Motion as employed in the present mules is shown in Fig. 28, Plate 81, which is a plan of the main driving shaft or "rim shaft" A of the machine, carrying the large "rim wheel" Z or double-grooved pulley driving the whole of the mule spindles by the endless cords X X, Fig. 22, passing round the pulleys Y Y. On the boss of the loose pulley B is a pinion C, which through a train of intermediate wheels D D drives in the reverse direction and at the required slower speed the spur wheel and friction cone E, also running loose upon the shaft A and sliding longitudinally upon it. This friction cone engages in a corresponding hollow cone inside the fast pulley F; and when the driving strap is shifted from the fast pulley F to the loose pulley B for the purpose of backing off, the friction cone is also brought up against the fast

pulley, thereby first arresting by friction the forward motion of the driving shaft A, and then giving it the reverse motion for backing off.

Roberts' Winding Quadrant for regulating the winding of the threads, by diminishing the speed of the spindles in proportion as the diameter of the cops increases, is shown in Fig. 29, Plate 82. This very ingenious contrivance has never been superseded, and is employed in almost every self-acting mule at the present day. The quadrant A turns upon a fixed centre C in the frame of the mule, and a pinion B gears into it, which is driven by a band and pulley receiving motion from the traverse of the carriage G, the arrows indicating the direction of motion during the run-in of the carriage. The grooved arm D of the quadrant contains a double-threaded screw, by which the sliding nut E is traversed outwards from the centre of motion C towards the extremity of the arm D. When the carriage is at the outer end of its stretch, the arm D stands inclined 12° outwards from the vertical, as shown by the dotted lines; and during the run-in of the carriage it turns inwards through an arc of 90°. A chain F attached to the nut E is coiled round a drum H inside the carriage G, and as the carriage recedes from the quadrant arm during the run-in the chain thus causes the drum to rotate, and thereby drives the spindles T through the intervention of the tin roller I geared to the drum H. At the commencement

[redacted]

of the threads W during the winding. The depression of the counter-faller towards the lower part of the cop J brings down the end of a governing lever upon a horizontal strap, which passes round a pulley on the headstock of the mule and round another on the centre shaft C of the quadrant; and on this shaft is a bevil pinion gearing into a second bevil pinion on the end of the double-threaded traversing screw in the arm D; so that when the governing lever is depressed upon the strap by the counter-faller, the forward motion of the lever as the carriage runs in drags the strap along with it by friction and turns the shaft C forwards, sliding the nut E outwards towards the circumference of the quadrant. At the moment when the backing-off motion has ceased and the carriage begins to run in for winding up the stretch of thread spun, as shown in Fig. 24, the counter-faller wire V is at its highest working position, compensating for the additional length of thread that has been uncoiled from the top of the spindle in backing off after the spinning of the stretch was completed. The nut E however, Fig. 29, is still at the same distance from the centre C of the quadrant as it was at the conclusion of winding the previous stretch; and therefore, as the diameter of the cop is now greater by winding the new layer of thread outside the previous one, the winding of the new stretch commences rather too fast, and begins at once to take up the length of thread given out in the backing off. The counter-faller V is thus depressed, and by means of the governing lever slides the nut E further out from the centre C, until the speed of winding is sufficiently diminished to allow the counter-faller to rise again high enough for lifting the governing lever off the strap. It will be seen that, in consequence of the arm D describing the quadrant of a circle, the horizontal motion of the nut E in the winding of each stretch is greatest at the commencement of the winding and gradually diminishes as the carriage runs in; and the effect of this is that the speed of winding is gradually increased towards the end of each stretch. By this means the threads are wound uniformly upon the cops, with an equal degree of tightness throughout.

The whole mule is driven by a strap $3\frac{3}{4}$ inches broad, running over the fast pulley F, Fig. 28, on the rim shaft A, and travelling at about 1670 feet per minute or about 19 miles per hour. The driving power required is about 1 indicated horse power per 230 spindles, or $4\frac{1}{4}$ horse power for each mule containing 1000 spindles. The speed of the endless cord X passing round the rim wheel Z, Fig. 22, is 2640 feet per minute or about 30 miles per hour. The carriage of the mule makes 3 to $3\frac{1}{2}$ double journeys out and home per minute, the length of stretch being 63 inches; but the velocity varies at different parts of the traverse, the carriage being taken in by a pair of scrolls in the centre of the machine, and drawn out by three spiral grooved pulleys keyed upon a shaft running the entire length of the mule, one pulley being in the middle of the shaft and one at each end. The length of the carriage being upwards of 100 feet, a parallel motion is required for keeping the carriage straight; and this is obtained by a horizontal traversing pulley at each end of the carriage, traversing along fixed cords and thereby made to revolve; and these two pulleys being also coupled together by a crossed cord are compelled to revolve at the same rate, and consequently cause each end of the carriage to travel at the same rate. There are three pairs of drawing rollers P, Fig. 22, by which the rovings are drawn about 8 times before being delivered for spinning. The last pair of rollers delivers the rovings at a speed of 26 feet per minute, until the carriage G has run out the [redacted]

an average number of yarn, such as No. 32, which is such a quality that 32 hanks of 840 yards each weigh together 1 lb.; the time of winding each stretch is about $3\frac{1}{2}$ seconds. The velocity of the spindles is about 390 revolutions per minute in winding, and in twisting the speed ranges from 8000 down to 3000 for coarse work, a common average being about 6500 to 7000 revolutions per minute. In backing off the velocity of revolution is about 1-20th of that in twisting. The direction of rotation of the spindles is the same in twisting and in winding, and the thread is wound on in a right-handed spiral when spinning twist, and left-handed when spinning weft. Fig. 27, Plate 81, shows full size the conical form of the top of the spindles for the purpose of letting the thread slip off freely at each revolution in twisting; and the two lines G and H show the extreme inclinations of the thread to the spindles during the twisting. The larger angle shown by the dotted line G, when the spindles are nearest to the drawing rollers, is about 145°; and the smaller angle shown by the full line H is about 105°, when the spindles are at the outer extremity of the stretch. The spindles themselves are inclined inwards towards the drawing rollers at an angle of about 12° from the vertical, as shown in the drawing.

In a mule invented by Mr. John Robertson in 1834 and brought out with other improvements in 1839 by Mr. Smith of Deanston, the chief feature was the use of a mangle wheel for performing the principal motions and changes, including a method of increasing the amount of twist put into the threads during the last few inches of each stretch. The mule of Mr. James Potter also possesses some features, which, although they have not been largely adopted, have much merit in them. The carriage is moved in and out by an arm travelling through half a revolution, so that the motion begins and ends slowly and is quickest at the middle of the stretch. The winding on is effected by an adjustable conical drum, the larger end of which is of the proper size for winding upon the bare spindles, and the smaller for the full cops; the drum is traversed longitudinally on its shaft by a screw of differential pitch, to the nut of which is attached the winding chain that coils on the drum; and the position of the chain on the drum is changed rapidly at the

commencement of a set of cops, and more slowly as they fill up. This spiral cone drum was subsequently replaced by a contracting spiral pulley, which at full diameter drove the bare spindles, and gradually contracted as the cops approached completion.

The number of spindles in the self-acting mules has been gradually increased, until at the present time many mules contain 1000 spindles each. One pair of these mules requires the attendance of only one man and two boys, for cleaning the machines, setting in the rovings, attaching the broken threads, taking off the cops when full, and starting the machines to work again. In spinning No. 32 yarn (in which the weight of 32 hanks, each containing 840 yards, is 1 lb.), the production of the pair of mules per week of 60 hours is 45,000 hanks, or 21,477 miles per week, weighing 1406 lbs. The floor space occupied by one of the mules containing 1000 spindles is about 116 feet by 10 feet, leaving about 4 feet for passages at the ends of the mules in the modern mills of 120 feet width. The cost of a modern cotton mill for spinning No. 32 yarn, including building, machinery and accessories, steam engine and shafting, with fire-proof floors in the scutching and carding rooms and timber floors in the spinning rooms, averages 18*s.* per spindle; and one mill was built, during the cotton panic caused by the American war, for 15*s.* per spindle.

The progress made in cotton manufacture during the last [redacted]

whole of 64 million miles of yarn per day of 10 hours when in full work, or a length of thread equal to more than four times round the earth every minute.

The PRESIDENT remarked that the great extent of the advance effected in the production of cotton thread by the employment of the modern machinery was clearly illustrated by the particulars given in the paper just read as to the rate of spinning that was now attained. In India the old system of hand spinning still prevailed, as it had existed for hundreds of years past, the whole process being performed by the fingers; but from the particulars given in the paper of the remarkable results now attained by the improvements in machinery, the amount of thread spun by one of the present self-acting mules was as great as could be produced by 3000 hand spinners he believed, a pair of these mules requiring only the attendance of three persons, each of whom thus did as much work as 2000 could accomplish without machinery.

Mr. B. FOTHERGILL considered they were greatly indebted to the author of the paper for the clear account that had been given of the progress of cotton spinning, tracing the principles of the successive improvements from the first application of machinery down to the beautiful contrivances in use at the present time. The original machines of Paul and Arkwright, both the spinning machine, the carding engine, and the drawing frame, were fortunately all preserved now in the South Kensington Museum, having been obtained from Arkwright's family; they were in themselves of very great interest, and showed clearly that Arkwright and those who worked with him had a thorough practical knowledge of the nature of the fibre to be operated upon and the appropriate means to be employed. He was glad to hear it stated in the paper that the original invention of the principle of drawing by rollers was due to Paul, as the credit of the invention had until recently been given through mistake to others. It might perhaps not be generally known that the principle of Hargreaves'

spinning jenny was still adopted in spinning wool for the manufacture of cloth; only that instead of the roving of wool being held tight by a clasp, as in the original spinning jenny, a single pair of rollers was used, which delivered about 15 or 18 inches length of roving at a time to be twisted into thread, and the rollers were then stopped and the wool drawn out little by little by the carriage travelling along to the further end of the machine and twisting the rovings during the drawing. The principle on which this process was successful in producing a uniform degree of elongation throughout the length of the rovings was that wherever there was a thin place in the thread the greater portion of the twist ran into that part at first and thereby rendered it more difficult to be elongated than the thicker parts, which were thus drawn down in turn, and the production of an even thread was the result. The same principle was also adopted for spinning even the finer numbers of woollen yarn; but three pairs of rollers were then used, running at different speeds to aid in the drawing action and obtain greater uniformity of thread, instead of only a single pair.

Having assisted the late Mr. Roberts at the time of the invention of the self-acting mule, he remembered the introduction of the first of these machines at Mr. Birley's cotton mill in Manchester, and the great difficulties that had to be encountered from the opposition of the workpeople. Frequent breakdowns occurred at first, [redacted]

important to give prominence in the paper to the name of Paul, as the real originator of drawing by rollers, because it had hitherto always been customary through mistake to attribute this invention to Arkwright and Hargreaves. There was no question that the amount of mechanical ingenuity displayed during the last forty years in connection with cotton machinery was unparalleled in history; and the machine that was above all others the most interesting, and the one in which mechanical science had been brought most to bear, was the self-acting mule. A great many names were of course associated with the maturing of the many details in this machine and bringing it to its present state of perfection; but no one shone out so prominently as the late Mr. Richard Roberts, who first brought true mechanical principles to bear in the construction of the self-acting mule; and with the exception of details, the working of the machine was the same in principle at the present time that it had been when first introduced by him about 1825. Houldsworth was another whom it was necessary to mention particularly, because by the introduction of the differential motion he gave a character of perfection to roving machines which they never possessed before. The self-stripping carding engine now generally in use was originally introduced by Mr. Smith of Deanston; but it did not prove commercially successful until worked out into its present complete shape by Mr. Evan Leigh. There was little doubt however that the carding engine would find a great rival in the combing machine, which had been invented in France and recently introduced into this country for a different purpose; and though the machine was somewhat complex in its construction, and certainly quite distinct in principle from the carding engine, he believed it was destined to work a great revolution in the carding and stripping of cotton, and it was possible that combing might ultimately supersede carding altogether in the preparation of cotton. At present however the combing machine was comparatively in its infancy, so that it would be premature to enter into particulars respecting it; but he thought that on a future occasion it would afford good material for a separate paper on the subject.

Mr. Ramsbottom enquired whether the drawing action by means of pairs of rollers running at different speeds was due to Paul, or whether he simply used a single pair of rollers.

The President replied that they were indebted to Paul for the three pairs of rollers running at different speeds, so as to produce the drawing action between each pair which constituted the important feature of his invention.

Mr. W. Richardson mentioned that Paul was also the first who employed a revolving cylinder for carding, which had previously been done on a flat surface.

Mr. B. Fothergill observed that Paul had gone beyond the mere substitution of a revolving cylinder in place of a flat carding table, as he had also taken the great step of adding the series of carding rollers round the circumference of the main carding cylinder, which had been subsequently embodied and more thoroughly worked out in the carding engine of Arkwright, and further improved by the addition of the doffing knives for clearing the carding teeth during working.

Mr. W. Richardson remarked that the combing machine, which had been referred to as now being introduced for the preparation of cotton, was of particular value in connection with the great demand that had now sprung up for thread for sewing machines; a strong and clear thread was required without any breaks, and in order to [redacted]

DESCRIPTION OF THE MANCHESTER WATER WORKS.

By Mr. JOHN FREDERIC BATEMAN, of London.

The works by which the city of Manchester and its suburbs are now supplied with water were originally designed in 1846, and were commenced in the autumn of 1848; and the water was first introduced into the city at the end of 1850. Previously to this date the water supply had been gathered from various sources: for some twenty years the greater portion had been obtained from a limited tract of gathering ground within a few miles of Manchester; a small additional quantity had recently been procured from a well sunk into the new red sandstone at Gorton; and urgent deficiencies were made up by occasional supplies from the Ashton and Peak Forest Canals. The supply however was very inadequate and very impure. The present water supply is brought from the River Etherow, which divides the counties of Derby and Chester, deriving its supplies from the western slopes of the great chain of hills commonly called the backbone of England.

A general plan showing the drainage area and the entire course of the works to Manchester is given in Fig. 2, Plate 84; and Fig. 3, Plate 85, is a longitudinal section along the line of the works. The drainage ground lies nearly midway between Manchester and Sheffield, and extends over about 19,000 acres. It rises in parts to an elevation of about 1800 feet above the level of the sea, and about 1200 or 1300 feet above the deep and romantic valley of Longdendale, in which the main collecting reservoirs are situated, as shown to a larger scale in the plan Fig. 1, Plate 83. The district consists of the shales and sandstones which constitute the lower portion of the coal series, the upper millstone grit forming the cap of the steep escarpments on each side, while the lower

millstone grit, which may be said to separate the coal measure shales from the limestone shales, is found in the bottom of the valley. The water yielded by this geological formation is some of the purest in the world, being equal in general character to the water of Loch Katrine which supplies Glasgow. The spring water is especially brilliant, highly aerated, containing little or no foreign matter, and varying from about $1\frac{1}{4}°$ to $2\frac{1}{2}°$ of hardness according to Dr. Clark's scale, in which 1° of hardness is that corresponding to 1 grain of lime dissolved in 1 gallon of distilled water. The spring water is at all times most abundant, the district yielding much more than the usual quantity in proportion to the area from which the springs issue.

The average rainfall is about 50 inches per annum, and the average amount of water which may be collected about 40 inches, the net produce of three or four consecutive dry years being about 33 inches in each year. This quantity if wholly stored would afford a gross supply of about 39 million gallons per day; from which a certain stipulated guaranteed quantity has to be given as compensation to the mills on the streams interfered with, amounting to nearly 13 million gallons per day on the average of every day in the year; this leaves as the supply available for the city and its suburbs 26 million gallons per day. The quantity at present supplied is about 13 million gallons, so that there is water for double the population at the same rate of consumption.

[redacted]

set apart for the storage of pure water. The turbid or coloured water, being the water of floods, was to be stored in reservoirs specially allotted for the purpose; and after becoming comparatively pure by settlement and exposure to the atmosphere, it was either to be discharged into the river as compensation to the mills, or decanted off into the pure-water reservoirs for the supply of the city. The means adopted for carrying this object into effect were very simple and certain, and have proved perfectly successful. Each stream, whether large or small, separates itself by a simple arrangement, so that the pure water flows on direct to Manchester, or into the pure-water reservoirs, to be there stored for future use; and the turbid water flows into the turbid-water reservoirs or runs to waste down the river.

In Fig. 4, Plate 86, is shown the manner in which the separation of the water is effected in a large stream, the Crowden Brook. A weir A A is erected across the stream, with a passage B for water within the masonry beneath the top. In front or on the down-stream edge of the weir, a narrow transverse slot C opens into the passage beneath. When the stream is small, as indicated by the lower water line D D, or rather when not swollen by rain, and the water consequently perfectly pure, it drops through the slot into the passage B beneath, which communicates with a conduit to convey the water to Manchester or to the pure-water reservoirs. The slot C is constructed of such a width as to admit the whole stream, when it consists only of the pure water; but when the stream is swollen, as indicated by the upper water line E E, the velocity with which it passes over the weir is sufficient to carry it clear over the slot and down the face of the weir, into the ordinary river course or to the reservoirs for turbid water. Figs. 5 and 6 show the separating arrangement adapted to the case of a small stream, where the object is effected by a transverse slot C in a trough F crossing the pure-water conduit B. The water, when small in quantity and consequently pure, falling from an elevated ledge at the back of the slot, drops through the slot into the pure-water conduit B; but overshoots the slot when the quantity is large, and is then carried by the trough F in another direction.

The main impounding Reservoirs, shown in Fig. 1, Plate 83, are constructed in that beautiful part of the valley known as Longdendale, and are five in number. Three of them, namely the Woodhead, Torside, and Rhodeswood reservoirs, are constructed along the course of the River Etherow in the main valley, which they occupy for about 5 miles in length. The other two, the Arnfield and Hollingworth reservoirs, are placed on tributary brooks. The highest, the Woodhead reservoir, is at a level of 790 feet above the sea. The point at which the water leaves the lowest or Rhodeswood reservoir to be conducted to Manchester is about 13 miles distant from the city. To this point also is conducted all the spring water and pure water collected by the various conduits constructed for the purpose; and the joint volume of water is conveyed away by a common aqueduct* for the use of the city, as shown in Figs. 2 and 3.

This aqueduct is principally a covered conduit. It has a fall of 5 feet per mile, and passes under the Mottram ridge by a tunnel of about 3000 yards length, Fig. 3, and terminates in a reservoir at Godley near Hyde, about 8 miles distant from Manchester and 314 feet above the centre of the city. From this reservoir the water is conducted by a single line of cast-iron pipes of 40 inches diameter to two service reservoirs at Denton, about 4 miles from Manchester and 163 feet above the centre of the city; the average fall of the [redacted]

The total capacity of the five reservoirs in Longdendale is about 550 million cubic feet when full to the level of the overflow weirs, and their area about 400 acres. The heights of the embankments and the capacities of the several reservoirs are given in the following Table:—

Name of Reservoir.	Height of Bank.	Depth of Water.	Area of Reservoir.	Capacity of Reservoir.	
	Feet.	Feet.	Acres.	Cubic Feet.	Gallons.
Woodhead . . .	90	72	135	198,000,000	1,235,000,000
Torside	100	84	160	236,000,000	1,474,000,000
Rhodeswood. . .	80	68	54	80,000,000	500,000,000
Arnfield	67	52	39	33,600,000	209,000,000
Hollingworth . .	70	52	13	11,660,000	73,000,000
Godley		21	15	9,800,000	61,000,000
Denton No. 1 . .		20	7	4,800,000	30,000,000
——— No. 2 . .		20	6	3,700,000	23,000,000
Gorton Upper . .		26	34	19,500,000	123,000,000
——— Lower . .		29	23	16,000,000	100,000,000

The Manchester Water Works were at the time of their execution the largest works of the kind which had been constructed in this country, and in some respects the largest which had ever been constructed in any part of the world. Much therefore had to be specially considered, and nothing more so than the best form of the large valves, and the easiest mode of opening them under great pressure. There was little which then existed that could be advantageously imitated; everything had to be designed anew, with special reference to the work to be performed. In order to arrive at the best mechanical contrivance, public competition was invited upon a clear description of what was required and a short specification of certain conditions that were to be met. This resulted in many valuable suggestions, which were either adopted exactly as they were proposed, or modified and improved by subsequent consideration; and altogether a mass of information was in this way collected which could not perhaps have been obtained otherwise. It is but justice to say that, amongst the designs

for the larger apparatus, by far the best proposals and the best designs for the objects to be attained, taking all circumstances into consideration, were those received from Sir William Armstrong, who was accordingly the maker of all the large valves required for the works.

It was laid down as a principle that, whatever the size of the valve or the pressure under which it had to be worked, it should be so contrived as to be easily opened and shut by one man. No large valve then existing met this condition; and it frequently happened that a valve of no greater diameter than 24 inches, if it had to be worked under any considerable pressure, needed the combined power of half-a-dozen men. This requirement was met in all the large valves by dividing the valve into two and in some cases into three compartments, one of these being reduced to such a size as would be equivalent to a small valve, which could be easily opened by one man. This smaller division is first opened, and when it is open, the pressure behind the larger is to a great extent destroyed by the friction of the water flowing through the pipe beyond the valve; and the pressure is reduced to an amount equal to the extra head (never more than a few feet) required to pass the whole quantity through an aperture of the size of the small opening; or if the pipe beyond the valve merely requires filling, as soon as it is filled the pressure will be the same on both sides of the large valve. In either case the large valve can then be opened by one man. In Figs. 7, 8,

description of them is given in the paper on those works by Mr. Duncan at a former meeting of the Institution (see Proceedings Inst. M. E., 1863, page 174); they were also introduced in the Glasgow Water Works, as mentioned again in the paper by Mr. Gale on the subject (see Proceedings Inst. M. E., 1864, page 134). The great value of these valves is in the early stage of the works, when the pipes are first filled and subjected to the pressure they will ultimately have to sustain; but the valves should always be kept in working order, as pipes occasionally burst after years of work, without anything to account for the occurrence. In the Manchester Water Works some of these valves are discontinued, but others in suitable situations are kept in constant adjustment and are made to communicate with an alarum in the waterman's house, so that in the event of a pipe bursting and the valve closing he is instantly apprised of the accident.

In order to provide against the shock caused by stopping a large column of water many miles in length and flowing at a speed of several feet per second, a momentum valve opening outwards is placed upon the main behind each of the large stop valves and self-acting closing valves; and a description of this valve is also given in the former paper already referred to (see Proceedings Inst. M. E., 1863, page 175). These valves were also first used in the Manchester Water Works.

Self-acting valves called Reflux Valves are placed in the large pipes at the foot of all hills rising in the direction in which the water flows, for the purpose of preventing the water from flowing back again in the event of a pipe being emptied behind the valve by an accidental burst or otherwise. One of these valves in the 40 inch main is shown in Figs. 10 and 11, Plate 88, the flaps being made of leather, backed with cast-iron plates. The valves open with the current of water in the direction in which it ordinarily flows, as indicated by the arrow in Fig. 10, and close if the current is changed into the contrary direction.

A very important point in arranging water pipes on a large scale is the provision of ample means both for the rapid escape of

air from the pipes during the time they are being filled with water, and also for the subsequent discharge of the air which escapes from the water in its passage through the pipes and accumulates in the upper part of the bends formed by inequalities of the ground. Both of these operations, in order to be effectual, should be spontaneous or self-acting; and they are accomplished by means of the Self-Acting Air Valve shown in Fig. 12, Plate 89, which is mainly the invention of one of the writer's early assistants, Mr. Alfred Moore, to whom also is due the system of separating clear and turbid water as previously described. The construction shown in the drawing combines two air valves in a single casting, the large aperture A of $3\frac{1}{2}$ inches diameter being intended for the escape of the large quantity of air while the pipes are being filled with water, and the small hole B of 1-8th inch diameter for the escape of the air accumulating in the pipes when full of water. The gutta-percha balls C and D forming the valves are each 5 inches diameter, and when the pipes are empty they drop into the positions shown by the dotted circles; but as soon as the water reaches them they are floated upwards, and close the apertures A and B, preventing the escape of the water. The ball D closing the small hole B is made of such specific gravity that its own flotation together with the small pressure corresponding to the area of the minute orifice B is only just sufficient to hold it up against the orifice; and consequently, whenever the flotation is diminished by the slightest accumulation [redacted]

cover is removed, and a standpipe H is attached through which the water is drawn off. The screwed collar I on the bottom of the standpipe fits under two lugs K on the top of the valve box, and the standpipe being then screwed down forms a water-tight joint by means of a leather washer on the bottom. A spindle J passes down the centre of the standpipe, working through a stuffing-box and screwed bearing at the top and through a guide below, and terminating at the bottom in a cup which fits the ball valve E; so that by turning the spindle by the handle at the top, the ball is depressed, and the water flows out through the standpipe H. This standpipe is attached in a few seconds; and as the opening and closing of the valve is effected gradually by the employment of the screwed spindle J, all concussion is avoided.

The sluice valves shown in Plate 87, for discharging the water of the large reservoirs in Longdendale, are fixed at the outer end of the outlet pipes, which are 48 inches diameter. They consist of three slides or compartments A, B, and C, Fig. 9, forming together a complete circular area, which may be opened either separately or together. Each slide is opened by means of a gun-metal spindle D passing through a stuffing-box, the upper portion being cut into a square-threaded screw working in a gun-metal bush fixed in headstocks. They are opened and shut by worm-wheel gearing, as shown at G in Fig. 16, Plate 90. One man can with some difficulty open one compartment at a time when the valve is under 70 or 80 feet of pressure. Two men can do the work easily; but at the two deepest reservoirs, the Woodhead and Torside, the operation of closing and opening is performed by the agency of a small turbine wheel, supplied with water for power from watercourses above the level of the reservoir. This is shown in Fig. 16, and to a larger scale in Fig. 17. The turbine H, of which a plan is given in Fig. 18, is geared by the spur wheel and pinion J to the worm-wheel gearing G working the valve spindles DDD; and the water for driving the turbine is admitted to it through the pipe K by a hand stop-valve at L in the supply pipe M. A self-acting slide-valve is placed at I, connected to levers worked by tappets upon the valve spindles D, whereby the water is shut off

from the supply pipe K of the turbine and turned into the waste pipe N, as soon as the main sluice valve is either fully opened or fully closed; this arrangement prevents the possibility of accident, should the attendant neglect to stop the turbine in time by the hand stop-valve L.

On each separate conduit for collecting spring water or for conducting water from the large impounding reservoirs to the city are placed Gauge Sluices, shown in Figs. 19 to 21, Plate 91, which act not only as stop-gates, but also as gauges for determining the quantity of water passing along each conduit. This is effected by gauging rods placed before and behind the sluice A, which is of definite dimensions; and by an index B which rises with the door of the sluice and indicates the extent that the sluice is opened. This index is shown to a larger scale in Figs. 22 and 23. By taking the difference in the level of the water behind and in front of the sluice, and the area of the opening through which the water is discharged, the application of the proper formula determined by experiment affords at all times the means of ascertaining the quantity of water passing through.

Where the water is finally discharged into the Godley reservoir it is passed through a basin A, Fig. 27, Plate 92, in one side of which a Gauge Plate B is erected, whereby the quantity of water passing is daily measured. This plate contains three rectangular

[redacted]

ordinary rule for determining the practical velocity of the discharge of water through an orifice in a thin plate is to multiply the square root of the head or pressure by the coefficient 5·1 or 5·4. The coefficients for velocity however, determined by the experiments made with these three openings, were 5·6 for the opening with the curve outside, 7·0 for the curve inside, and 7·6 for the double curve both inside and outside; the third opening thus giving a velocity nearly equal to the whole theoretical velocity due to the height of fall, for which the coefficient is 8·04. The openings in the gauge plate were entirely submerged on the inside, the depth of water in the basin A, Fig. 27, varying from about 1 foot to 4 feet above the centre of the openings; and the water had a free discharge on the outside, as indicated in Fig. 27, falling into a tank C of a given size, so that the quantity passing during any time was correctly measured.

Before the water leaves the Godley reservoir and again before it leaves the Denton service reservoirs, it is strained through copper wire-gauze strainers, the whole vertical area through which the water passes being about 800 square feet. The copper wire-gauze first tried consisted of 72 strands per square inch, but that was found to be too fine, as the apertures got rapidly closed, and the gauze became as tender as brown paper and was easily torn and broken. The gauze now used consists of copper wire made with 40 strands per square inch, which seems well suited for the purpose. No other filtration of the water is attempted or needed, as the water is always perfectly pure. The service reservoirs are from 18 to 20 feet deep, carefully paved on the slopes and bottom, and there is no vegetation in the reservoirs or in the conduits; and the only object of the strainers is to prevent extraneous floating matter in the water from passing into the pipes. The system of separation adopted as previously described wholly supersedes the necessity of filtration.

There remains to be noticed the means adopted for Gauging the Compensation Water that has to be given off to the millowners. This is shown in Fig. 28, Plate 93, which is a general plan of the arrangement, and Fig. 29 is a longitudinal section through the gauge basin and test basin; Figs. 30 to 34, Plate 94, show the

principal details to a larger scale. The water is first admitted into the masonry gauge basin A, in which the level is carefully regulated by means of sluices B. It then passes through two apertures in vertical gauge plates C, by which the quantity of water passing through may be accurately computed according to the pressure on the aperture, by employing the coefficient determined by the Godley experiments. In order to ensure a uniform discharge of water under a varying head, the gauge plates C, Figs. 30 to 32, are each fitted with a slide actuated by the float D, whereby the size of the gauging orifice is rendered self-adjusting, and varies inversely as the height of the water in the gauge basin A, thus giving a constant discharge. But in order to prevent the possibility of dispute, the water discharged from each gauge aperture C into the river below is carried by a trough E across a square test basin G, 30 feet square and 10 feet deep. In the bottom of each trough E, Fig. 30, is placed a tumbler I in a horizontal position, turning on an axis in the centre, and this tumbler ordinarily forms the floor of the trough and the water passes over it, as shown enlarged in Fig. 33. But on drawing back the hand lever H into the position shown by the dotted line, so that the extremity of the tumbler just clears the edge F of the trough, the tumbler is instantaneously reversed by the stream of water and turned vertically across the trough, where it is caught by the stop J, as shown in Fig. 34. In this position [redacted]

interested in the supply of the compensation water, and the quantity discharged may at any time be tested by this means.

Mr. W. Fairbairn regretted that Mr. Bateman was prevented from being present at the meeting; and among the various features of the works that had been described in the paper just read, one of the most interesting he thought was the very simple arrangement for separating the turbid water from the pure in the streams supplying the storage reservoirs. In time of floods the water was found to be so turbid as to be unfit for immediate domestic use, and by the simple means of a narrow transverse slot across the bed of the stream the separation of the turbid water was effected with complete success, and the arrangement was entirely self-acting; the turbid water of the swollen stream overshot the aperture and passed on down the river, while the pure water when the stream had become reduced to its natural size dropped through the slot and was led away to the city or into special reservoirs. The plan of dividing the large sluice valves into three portions, so as to allow of opening at first a small portion only of the entire area, instead of having to open the whole valve at once, was found to answer very well, enabling one man to open and close the valves of the large mains, as the pressure was to a great extent relieved off the valve as soon as a small area was opened for the passage of the water. The self-acting air valves for allowing a constant escape of the air accumulating in the water pipes were found to act very efficiently, the smaller air-hole being opened by the descent of the ball whenever there was the slightest accumulation of air, and as soon as the air had escaped the ball rose again and closed the orifice, preventing any escape of water. The hydrant or fire-cock made with the gutta-percha ball valve was now coming into general use both in this country and abroad, on account of its convenience and great simplicity of construction.

Dr. Downing enquired about the sections of the apertures in the gauge plate at Godley reservoir (Figs. 24, 25, and 26), whether they

were vertical sections of the apertures, and whether the apertures were of considerable width in proportion to their height; and also whether the section of the lip was the same at the vertical ends of the apertures as at the top and bottom.

Mr. W. Fairbairn replied that the sections shown in the drawings were vertical sections of the apertures in the gauge plate, and each aperture was a rectangle of 6 feet width by 6 inches height, the section of the lip in each case being the same at the two ends of the aperture as at the top and bottom.

Dr. Downing enquired how far the three coefficients obtained with the three different sections of lip had been found to be affected by variation in the depth or head of water producing the flow through the gauge apertures; and whether it had been found that a different form of section would be preferable with a change of head.

Mr. W. Fairbairn replied that no other section of aperture had been used than the three sections shown in the drawing (Plate 92); and the result of experiments made upon the effect produced by alterations in the head of water was that the coefficient for velocity of the issuing stream was little affected by variations in the head, except when the head was less than about one foot or double the height of the aperture. The particulars were shown by the following table, which gave the mean results of a number of experiments made at Godley reservoir in August 1852:—

[redacted]

Mr. H. MAUDSLAY observed that the effect of the form of the edges upon the flow of water through an orifice was a most interesting question, and the results obtained from the experiments with the apertures shown in the drawing were of very great practical value. In many other instances, such as the nozzles of fire-engine hose, it was particularly important that the correct form of aperture should be arrived at, in order to obtain the greatest result in the discharge with a given pressure of water. In the section (Fig. 26) presenting a curve to the water both on entering and on leaving the aperture, he enquired whether the curvature of the lip bore any definite proportion to its thickness, and also to the height or width of the aperture.

Mr. J. KENNAN enquired whether it would not have been preferable to take a considerably larger radius than $2\frac{1}{2}$ inches for the curve forming the approach to the gauge aperture, so as to give a greater length of curved surface for guiding the water towards the aperture.

Mr. W. FAIRBAIRN replied that the curvature of the edges of the gauge apertures had been determined without reference to the height or width of the aperture, the radius being taken at half the thickness of the lip; and he could not say whether a larger radius would have been preferable, but that might probably have been the case. The experiments made with the apertures shown in the drawing confirmed the well established fact that water would not turn sharp corners without occasioning a loss; and it was necessary therefore to round off the edges of the aperture on both faces, by which means the discharge obtained in practice had now been brought up to within 5 per cent. of the total discharge theoretically possible, as shown by the experiments.

Dr. DOWNING understood that for the purpose of taking off the water for the supply of Manchester from the storage reservoirs in the Longdendale valley the discharge pipes had been laid through the bottom of the reservoir embankments, and had been crushed in subsequently at one of the reservoirs by the settling of the bank after its completion; and he enquired how this difficulty had been obviated, and how the water was now taken off from the reservoir.

He understood also that syphons had been partially employed for the purpose, and enquired what had been the effect obtained with them.

Mr. W. Fairbairn replied that the construction of the embankments for the storage reservoirs had been attended with great difficulties, and the case was very different from that of the Loch Katrine Water Works, where the supply of water was already impounded by walls of solid rock consisting of the hardest mica slate, and it was only necessary to cut a passage for drawing off the water. At the Longdendale reservoirs on the contrary the ground on both sides of the valley had been disturbed by landslips, and was still subject to occasional movements by subsidence or settlement. The discharge pipes from the reservoirs had been laid in the solid ground beneath the embankments. In the case of the Rhodeswood reservoir no alteration had taken place in the pipes, and the water was still discharged by this means; but at the Torside reservoir, the largest of the three great reservoirs in the valley, the ground beneath the embankment had become stretched by the weight of the superincumbent material, and drew the pipes to some extent asunder at the socket joints, crushing them also slightly. This evil had been obviated by driving a tunnel through the solid hill at one end of the embankment and laying fresh discharge pipes within this tunnel. There were two pipes in the tunnel, one 48 inches diameter and the other 24 inches, the latter being a syphon pipe by which the last 15 feet depth of water could be

The President proposed a vote of thanks, which was passed, to Mr. Charles P. Stewart and the Local Committee for the excellent arrangements they had made for the meeting of the Institution in Manchester; and also to the authorities of the Mechanics' Institution for their kindness in granting the use of the Lecture Theatre for the purpose of the meeting; and to the several Railway Companies for the special facilities they had so kindly afforded to the Members for attending the Meeting in Manchester and the Excursions in connection with the meeting.

The Meeting then terminated. In the afternoon the Members visited the Whitworth Ordnance Works and the various engineering establishments and other works which were opened to their inspection during the days of the meeting.

In the evening the Members and their friends dined together, in celebration of the meeting of the Institution in Manchester.

On Thursday, 2nd August, an Excursion was made by the Members from Manchester, to visit the Cotton Machinery Works and Machine Brick Works of Messrs. Platt at Oldham, and some of the Cotton Mills adjoining; and the Members were very handsomely entertained by Mr. John Platt, M.P., at his residence, Werneth Park. They returned in the afternoon by special free train, granted by the Lancashire & Yorkshire and Manchester Sheffield & Lincolnshire Railways, visiting Messrs. Beyer Peacock and Co.'s Locomotive Works at Gorton, and the Ashbury Co.'s Railway Carriage and Iron Works at Openshaw.

On Friday, 3rd August, an Excursion was made by the Members from Manchester by special train, on the invitation of the President, to his residence, Stancliffe Hall, Derbyshire, where they were most hospitably received and entertained by the President; visiting also Chatsworth and Haddon Hall.

PROCEEDINGS.

15 November, 1866.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 15th November, 1866; Sampson Lloyd, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the Rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting.

The following Members were nominated by the meeting for the election at the Anniversary Meeting:—

PRESIDENT.

John Penn, ... London.

VICE-PRESIDENTS.

(Six of the number to be elected.)

Charles F. Beyer, . . . Manchester.
William Clay, . . . Liverpool.
Edward A. Cowper, . . . London.
Thomas Hawksley, . . . London.
Robert Hawthorn, . . . Newcastle-on-Tyne.
Edward Humphrys, . . London.
Sampson Lloyd, . . . Wednesbury.
Henry Maudslay, . . . London.
W. Montgomerie Neilson, . Glasgow.
John Ramsbottom, . . . Crewe.

COUNCIL.

(Five of the number to be elected.)

ALEXANDER ALLAN, . . .	Worcester.
CHARLES EDWARDS AMOS, .	London.
JOHN ANDERSON, . . .	Woolwich.
FREDERICK J. BRAMWELL, .	London.
ROBERT BROAD, ...	Tipton.
CHARLES COCHRANE, . .	Dudley.
THOMAS GREENWOOD, . . .	Leeds.
WILLIAM MENELAUS, . .	Merthyr Tydvil.
C. WILLIAM SIEMENS, . . .	London.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

SAMUEL BAKER, ...	Liverpool.
GEORGE BARKER, . . .	Stoke-upon-Trent.
JOHN ADDISON BIRKBECK, . .	Chesterfield.
WILLIAM CRAVEN, . . .	Manchester.
ALFRED C. DOWNEY, . . .	Middlesbrough.
JOHN ELCE, ...	Manchester.

[redacted]

George Peel, Jun., . . .	Manchester.
Thomas Edward Day Plum, .	Manchester.
Charles Talbot Porter, . .	Manchester.
John Price, ...	Sunderland.
William Putnam, . . .	Darlington.
James Ramsden, . . .	Ulverstone.
Edward Windsor Richards, .	Ebbw Vale.
Thomas Robson, . . .	Fence Houses.
Edward Fisher Smith, . .	Dudley.
William Smith, . . .	Glasgow.
Robert Watson, . . .	Bishop Auckland.
Emile Watteeu, . . .	Middlesborough.
William Wray, ...	Burton Stather.

ASSOCIATE.

John Crossley, ...	St. Helen's.

GRADUATES.

Robert Harry Humphrys, . .	London.
Frederick Ryland, . .	Westbromwich.

The following paper was then read:—

ON SELLERS' SELF-ADJUSTING INJECTOR, AND OTHER IMPROVEMENTS ON GIFFARD'S INJECTOR.

By Mr. JOHN ROBINSON, of Manchester.

In the experience of the working of Giffard's Injector for the supply of water to steam boilers, which has now come so extensively into use both in this country and abroad, various requirements have been found to arise; and for the purpose of meeting these, several improvements of the instrument have been introduced, one of the most remarkable of which is an arrangement invented by Mr. William Sellers of Philadelphia, the manufacturer of the injector in the United States, to obviate the necessity of adjusting by hand the quantity of water supplied to the injector, and thus render the instrument to that extent self-adjusting.

In the original Giffard's injector shown in Fig. 1, Plate 95, the quantity of water allowed to reach the combining cone B is adjusted by means of the external regulating hand-screw F, which by raising or depressing the steam cone A increases or diminishes the annular opening for water. In Sellers' self-adjusting injector this opening is adjusted by the application of a piston in a cylinder, actuated by the amount of pressure or of vacuum existing alternately in the overflow chamber, according as the supply of water is in excess or deficient.

The construction of the self-adjusting injector is shown in the vertical section, Fig. 4, Plate 96, with the working portion enlarged in Fig. 5. A is the steam cone, B the combining cone, C the receiving cone; and the admission of steam through the steam cone A is regulated as hitherto by the handle D of the steam spindle I. The combining cone B at its base is so made as to form a piston E, which separates the water chamber G from the overflow chamber O. The interval J forms the entrance to the

receiving cone C, and also to the overflow chamber O, as shown in the transverse section, Fig. 6. The boiler valve H prevents the water returning from the boiler; and K is a waste cock, which when open allows the water and steam to issue into the atmosphere.

The mode of working the instrument is as follows. The waste cock K being first opened, the supply of water admitted from the tank is allowed to flow out through the waste; and the steam being then turned on by the handle D, an immediate increase takes place in the volume of water escaping at the waste cock, showing that the jet has been established. The waste cock is then closed, and the water flows into the boiler through the valve H. In case there should be too much water admitted to the combining cone B, the superabundance will be driven into the overflow chamber below the piston E, and will raise the piston so as to diminish the annular space between the combining cone B and the steam cone A, and thus reduce the water supply until the quantity admitted is in exact proportion to the supply of steam. The relative positions of these cones will then remain the same until some change takes place in the pressure of the steam. Supposing the pressure of the steam in the boiler should increase, so that a larger quantity of steam is discharged through the steam cone, the increased velocity of the jet will carry along with it into the boiler some of the water which had previously escaped through the opening J into the overflow chamber, and will thus produce a partial vacuum under the piston; the pressure of the water will then cause the piston to recede from the steam cone and admit more water, until the proper proportion is again established. At the junction of the water branch G with the main body of the injector a small valve L is provided, Fig. 5, opening outwards; and the escape of steam from this valve gives warning that the injector has ceased working from want of water, similarly to the escape of steam from the overflow pipe M in the original injector, Fig. 1.

In many boilers, such as those having a small water and steam capacity compared with their heating surface, and where the demand for steam is very irregular, the variations in the steam pressure are considerable and frequent, and the amount of attention

required for regulating an ordinary injector becomes somewhat inconvenient; under such circumstances the ingenious and simple arrangement now described for rendering the injector self-adjusting will be found extremely useful. It is evident that this arrangement of injector does not permit any overflow to take place after the injector is once started. Also as no air can get admission to the receiving cone of the injector, in consequence of there being no open overflow pipe, the entering water jet is not impeded in its progress by the contact of air tending to enter with it. In injectors having an open overflow, air can gain access to the entering water jet, and the quantity of water passing into the boiler is consequently diminished.

An arrangement for rendering the self-adjusting injector also self-starting has been contrived at the writer's works, in order to obviate the necessity for opening and closing by hand the waste cock K, Fig. 4; for when this cock has to be opened and closed by hand by the attendant at each time of starting the injector, it increases the number of manipulations, and may therefore perhaps be considered as a slight objection to the instrument in that form. In the improved self-starting injector, shown in Fig. 7, Plate 97, and enlarged in Fig. 8, the spindle of the boiler valve H carries a smaller conical valve S, which when the injector is not at work is always kept open by the pressure of the boiler upon the valve H, as shown in Fig. 8. When therefore the steam is first turned on for starting the injector, the water is at first allowed by the valve S to escape through the waste pipe Q; but as soon as the jet is established, the valve H opens to the boiler, and at the same time closes the conical valve S, and stops the escape through the waste pipe, as shown in Fig. 7. This arrangement has the advantage not only of rendering unnecessary the opening and closing by hand of the waste cock, but also of showing very clearly when the injector ceases working; because when that happens the boiler valve H is closed by the back pressure from the boiler, thereby opening simultaneously the valve S and allowing the steam and water to escape through the waste pipe Q.

In Fig. 2, Plate 95, is shown the improved arrangement of the ordinary injector with hand adjustment, designed by the writer and Mr. Gresham, which has now come into extensive use in place of the original form of injector. In the original injector, shown in Fig. 1, the combining cone B and receiving cone C are stationary, and the admission of water is regulated by sliding longitudinally the steam cone A, which is carried upon the extremity of a hollow cylinder N, passing through a stuffing-box at the top of the instrument, and requiring also an internal ring of packing at P, in order to prevent the steam from blowing through into the water chamber. With high pressure steam, such as 120 lbs. having a temperature of 350° Fahr., this internal packing becomes injured by the constant exposure to the high temperature whilst working, and involves the trouble of frequent renewal; and in order to obviate this difficulty, the improved injector shown in Fig. 2 is constructed with the converse arrangement of the cones, the steam cone A being made a fixture in the instrument, while the combining cone B and receiving cone C are cast together in a single piece sliding longitudinally, and are moved by the internal rack and pinion R. By this means the necessity for any internal packing is avoided, as no internal steam-tight joint is required; and at the same time the stuffing-box at the top of the sliding cylinder N, Fig. 1, is also done away with. The sliding cones B and C, Fig. 2, require only to be turned originally to an easy fit in their external cylindrical guides, as it is not necessary for these joints to be absolutely water-tight. The only additional requirement involved in this arrangement is the stuffing-box for the spindle of the pinion R, which is packed externally and has only to be made water-tight, in contrast with the internal steam-tight packing P in the original injector, Fig. 1.

The progress that has been made in increasing the delivery of water by the improvements effected in the injector is shown in the accompanying table, which gives the deliveries obtained at different pressures of steam with the self-adjusting injector and the rack and pinion injector, in comparison with the theoretical delivery as originally calculated by M. Giffard:—

Pressure of Steam. Lbs. per square inch.	Delivery in gallons per hour.		
	Giffard's original calculation.	Rack and Pinion Injector. Fig. 2, Plate 95.	Self-Adjusting Injector. Fig. 4, Plate 96.
Lbs.	Gall.	Gall.	Gall.
10	246	420	480
20	348	590	655
30	427	665	780
40	493	745	865
50	551	780	900
60	604	936	1081

Temperature of supply water 85° Fahr.

From this table it will be seen that considerable progress has been made in developing the capabilities of the injector since it left the hands of the inventor. In the case of the rack and pinion injector, shown in Fig. 2, the increased delivery may be attributed partly to the better vacuum obtained in the water chamber by the adoption of the fixed steam nozzle without packing, and partly to the more perfect concentration of the steam current upon the water current, in consequence of the greater length to which the steam cone A is inserted into the combining cone B. In the case of the self-adjusting injector, shown in Fig. 4, the steam cone A is also fixed; and as the exact quantity of water which the steam is capable of taking up is always admitted to the instrument by its self-adjusting property, it is evident that the injector once having the steam adjusted for the maximum delivery continues to deliver the maximum quantity of water which the pressure of the steam at any moment renders possible. On the other hand, in the case of an injector requiring the water admission to be adjusted by hand, it is impossible for the injector to produce constantly the maximum effect of water delivery when there is a continual variation in the pressure of steam, because the water supply cannot in ordinary practice be constantly adjusted by hand to suit the varying pressure.

There appears to the writer to be a possible drawback to the application of these self-adjusting injectors in cases where a high temperature of supply water is to be used, and especially where that temperature varies, as in the case of a locomotive engine. This

drawback consists in the probability that under such circumstances the injector might be difficult to start, because there is no open overflow pipe for allowing the surplus water to escape, and therefore a greater quantity of water cannot be used to condense the steam jet than can be admitted into the boiler in a given time through the receiving cone of the injector. With the ordinary open overflow however a larger quantity of water than can obtain access to the boiler may be admitted to condense the steam current, the surplus escaping at the overflow; and thus a feed can be established, although overflow may at the same time take place.

A simple means has also been arranged by Mr. Sellers for raising the supply water by the action of the injector itself, where the supply is at some depth below the level at which it is convenient to fix the injector. The arrangement adopted for this purpose is shown in Fig. 8. A small hole is drilled up the centre of the steam adjusting spindle I, throughout the length that is within the steam cone A, and four small transverse holes at the top admit the steam to pass down through the interior of the spindle as soon as the conical valve T is slightly opened. The combining cone B is so arranged as not to close the water passage entirely when the piston E is at the extremity of its range, as shown in Fig. 8, but to leave still a small annular space for the admission of the water from the water chamber G. The effect therefore of slightly opening the valve T is to allow a small quantity of steam to issue from the hollow steam spindle at a high velocity, and pass out through the waste pipe Q, taking with it any air which may exist in the water chamber G; by this means a greater amount of vacuum is produced in the water chamber than would be created if the steam were allowed to pass at a lower velocity through the annular orifice of the steam cone A. The conical valve T, Fig. 8, which was suggested at the writer's works, is also found to be a better method of shutting off the steam than by stopping the steam cone A with the end of the spindle I, as in Fig. 5; and the application of the valve T, Fig. 8, reduces the starting process to one operation, because when the water from the tank and the steam from the boiler are turned on, it is only necessary

to turn up the steam spindle by the handle D, Fig. 7, in order to start the injector.

Endeavours have been made by Mr. Barclay of Kilmarnock and others to construct an ordinary Giffard's injector in such a manner that it will draw water from a considerable depth; and this has been successfully accomplished to the extent of lifting the water from a depth of 15 or 18 feet below the water chamber of the injector, the temperature of the supply water being 60° Fahr. The construction of injector employed for this purpose is shown in Fig. 10, Plate 98; and the success is attributable to the care taken to obtain a better vacuum in the water chamber G by means of double stuffing-boxes U and V. One of these U prevents the escape of steam into the air, and the other V prevents the entrance of air into the water chamber G. Considerable importance is also attached to the advantage of a shielded steam cone A, shown to a larger scale in Fig. 11, the extremity of the cone being surrounded by an external casing, leaving an air space between of ¼ inch width closed at the bottom, which serves as a non-conductor to prevent the steam from being cooled and cause it to preserve its full heat to the very extremity of the steam nozzle. The steam adjusting spindle I is also made to project through the steam cone A into the combining cone B in the same way as in the original injector, Fig. 1, so as to secure not only an annular steam jet but also an annular combined jet; and the spindle is steadied near the extremity by the guide X, Fig. 11, to keep it truly central with the jet.

Another arrangement of injector for the same object is shown in Fig. 12, where the sliding steam nozzle has only a single stuffing-box W, which prevents the ingress of air to the water chamber; and the steam entrance is fixed upon the sliding steam nozzle, and moves with it, so as to preclude the necessity for a second stuffing-box to prevent leakage of steam. This construction requires however a flexible steam pipe, in order to allow for the motion of the sliding steam nozzle. When the injector is used for lifting water from a lower level, the steam cone A is first turned down by the regulating screw F to its extreme lowest position, as shown by the dotted lines, leaving a small annular passage for water between the steam cone

and the combining cone. The steam spindle I is then turned once round, which gives sufficient opening for the amount of steam required to exhaust the water chamber G. As soon as the water is seen to issue from the overflow pipe M, the handle F is turned so as to raise the steam cone A to a position suited to the pressure in the boiler, and the steam spindle I is drawn back until the overflow ceases.

It is evident that in these two arrangements of injector, as shown in Figs. 10 and 12, no leakage of either air or steam into the water chamber G can take place, to impair the vacuum capable of being produced by the jet of steam issuing through the combining cone.

The CHAIRMAN thought the self-adjusting injector described in the paper just read was a remarkably elegant and ingenious application of science to engineering practice; and he enquired how long it had been in use, and whether the new improvement could be adapted to injectors already existing on the previous plan.

Mr. ROBINSON replied that the self-adjusting arrangement had been devised with special reference to locomotive engines, to meet the constant variations in their steam pressure during ordinary work; and a great number of the improved injectors were already in use on locomotives in the United States, and it was now being endeavoured to render them suitable as far as possible to the requirements of locomotives in England. One obstacle at present to the adoption of the self-adjusting injector was that, as the overflow was entirely closed in, it made no noise when at work; and the enginemen did not like a quiet injector, having been accustomed to the old injector with the open overflow pipe, which they preferred on account of its making a noise in working, so that they could tell by the sound when it was at work. It would not be practicable to alter the previous injectors to the self-adjusting arrangement, as the extent of alteration required would amount to nearly as much as a new instrument.

Mr. C. W. Siemens remarked that, from the table given in the paper of the delivery of water obtained with the injector, it appeared that with a steam pressure of 10 lbs. the actual delivery obtained with the two forms of injector named was 420 and 480 gallons per hour respectively, while the calculated delivery was put down at only 246 gallons; and he enquired what was the explanation of this difference, and how it was that the delivery of the self-adjusting injector could be more than was given by calculation.

Mr. Robinson explained that the quantities put down in the column of theoretical delivery were those obtained from M. Giffard's original calculation of the delivery, and the calculation had been found to be incorrect, having been exceeded even by the early injectors, though only to a comparatively small extent at first. By subsequent improvements however in the proportions of the instruments, the maximum delivery had been still further increased, and this increase had been much more considerable in England than in France. Another point on which a mistaken idea had at first been entertained was the area of the steam cone, which had been made smaller in proportion for higher pressures of steam; whereas in reality a larger area was requisite with a higher pressure, in order to obtain a larger quantity of steam and so increase the velocity of the jet, and thus overcome the increased resistance of the boiler; and the greater degree of success attained in England with the injector, particularly at higher pressures, was to be attributed mainly to the adoption of a larger proportionate area for the steam cone.

Mr. F. J. Bramwell remarked that the quantities given in the table as Giffard's original calculation appeared to increase in the proportion of the square root of the increase in pressure, the delivery being put down at 246 gallons with a pressure of 10 lbs., while with four times that pressure or 40 lbs. the delivery was twice as great or 493 gallons. But by the two columns of actual delivery given in the table it appeared that the ratio of increase was somewhat less in practice, and therefore the proportionate difference between the calculated quantity as given in the table and the actual delivery obtained in practice would gradually diminish as the pressure increased.

The CHAIRMAN enquired what had been found to be the practical results of the improved injector as to its efficiency in working on locomotive engines.

Mr. ROBINSON said the self-adjusting arrangement was found a great improvement, by obviating the necessity for readjusting the admission of water to the instrument whenever any fluctuation occurred in the steam pressure; this adjustment had to be done by hand in the former injectors, and the engineman could not always readily attend to it just at the time when it was required. Another objection to the previous injectors was the constant dropping of water from the overflow pipe whenever the steam pressure fell, which was a great nuisance: this was entirely obviated in the self-adjusting injector, not merely by the fact of its being self-adjusting according to the varying pressure of the steam, but also by the whole instrument being entirely closed in, so that no escape of water at the overflow was possible after the starting cock had been closed at starting the injector to work.

Mr. C. W. SIEMENS asked whether in the self-adjusting injector the piston in the overflow chamber was always ready to act, or whether it was liable to stick; the self-regulating property of the instrument appeared to require considerable delicacy of action in the piston, especially in a small injector having a piston of small area. He enquired also, in regard to the self-starting injector shown in Fig. 7, in which the waste pipe was closed at starting by the opening of the boiler valve instead of by hand, whether it ever happened that the area of opening of the waste pipe was sufficient to discharge the whole jet of the injector, so that the boiler valve would not be opened by the jet at all; and he asked what proportion was adopted for the relative size of the waste aperture in order to prevent such an occurrence.

Mr. ROBINSON replied that it had been found in practice that the area of the waste aperture must not be more than 1½ times the area of the receiving cone, otherwise the jet of water might possibly continue to escape from the instrument without producing sufficient pressure on the boiler valve for opening it into the boiler. With regard to the piston by which the injector was rendered self-

adjusting, it had certainly been feared at first that the piston would be liable to stick, especially with bad water. But it was found on the contrary that the real difficulty was to prevent the piston from moving so rapidly and so violently as to injure itself by striking against the top of the cylinder, when the injector did not start at once. When the injector was stopped by shutting off the steam, the back pressure from the boiler in closing the boiler valve drove the piston back with great rapidity to the top of the cylinder; and he had delayed bringing forwards the self-adjusting injector until the results of actual working had shown how the piston stood the amount of shock to which it was subjected. As far as could be ascertained from the use of the injector upon locomotives, it appeared that the piston was so sensitive that a variation of only 2 lbs. per square inch in the steam pressure was sufficient to move it; the piston was therefore always moving, and never stood still while the injector continued at work. The first trial made with the self-adjusting injector had been on an engine employed in shunting; and with the ordinary injectors previously used the water constantly jumped out of the overflow pipe from the shocks in shunting; but as there was no open escape in the self-adjusting injector, it was feared the piston might be too sensitive when the engine struck a train, and that the escape of water into the closed overflow chamber might cause so much motion of the piston as to stop the current of the jet. In practice however this had not been found to be the case, and he believed the self-adjusting injector worked more steadily when shunting than the previous injectors having the open overflow.

The Chairman enquired whether any packing was employed for keeping the piston water-tight.

Mr. Robinson replied that in the first self-adjusting injector the piston had been made with two grooves filled with light metal packing rings, as shown in Fig. 5; but this had been found unnecessary, and he believed it was better not to make the piston so tight in the cylinder, in order to ensure its moving freely with the variations in the steam pressure. The piston was therefore now made without any packing, as shown in Fig. 8, being merely turned

to an easy fit in the cylinder; and it was not necessary for it to be absolutely water-tight, just as in the pneumatic despatch tubes a small clearance was left all round the piston, without interfering with the efficiency in working.

Mr. H. WOODS enquired whether by the employment of the self-adjusting arrangement there was any difficulty in working a large injector with only a small quantity of feed water. Supposing an injector were obtained large enough for feeding four boilers, he asked whether it could be conveniently employed for feeding one boiler only, whenever the other three might be out of work.

Mr. ROBINSON believed the improved injectors would allow of as great a range as 40 per cent. in the quantity of feed water, without the proper working being interfered with; and the self-adjusting arrangement would certainly have an advantage in cases where a varying quantity of feed was required, because the water supply adapted itself to every change made in the steam supply within the limits of range allowed by the instrument. The alterations made in the proportions of the new injectors had had the effect he believed of slightly reducing the minimum delivery of the injector as compared with its maximum, though not to any material extent beyond the original injectors. With all large injectors there still remained the same difficulty as previously in supplying only a small quantity of feed to a boiler; and the only way to manage was to feed for a certain length of time and then shut off, which was certainly a very inconvenient plan and only partially obviated by the self-adjusting arrangement. In travelling recently a considerable distance by railway he had been able to tell by the sound of the injector when it was at work or not, as it was one of the former sort with an open overflow; and he observed that the engineman started the injector whenever he stopped the train, and *vice versâ*, using the surplus steam to feed the boiler when not running, which appeared a very rational way of dealing with the difficulty of having an injector larger than was required for the work to be done.

Mr. W. HACKNEY enquired how the water was prevented from escaping at the small outlet valve placed on the water branch, as shown at L in Fig. 5, through which it was stated the steam would blow out whenever the injector stopped working for want of water.

Mr. ROBINSON explained that the small escape valve was held down to its seat by a spring put upon it, which was adjusted to the head of water supplied to the injector and had its outlet above the highest water level, so that it did not allow the water to escape in ordinary working, and was only opened by the pressure of the steam when there was not water enough for the working of the injector. This valve however he thought was not at all necessary, except perhaps on locomotive engines, where it served to call the driver's attention when the injector ceased working, in the same way as the escape of steam from the open overflow pipe of the previous injectors.

Mr. E. A. COWPER enquired whether injectors had yet been employed with complete success for feeding marine boilers. In an early attempt for that purpose some objection had been made to the injector on the score of its occasionally failing; and he believed the difficulty in that instance was partly owing to the circumstance of a number of boilers being ranged in a line, supplied by one main feed pipe, with the injector delivering in at one end of the pipe. When the ship was rolling therefore, the whole column of water in the long feed pipe acted like a ram, giving a very considerably increased pressure for the moment upon the injector, as there was no air vessel to relieve it; and thus the injector had to work against a varying pressure, running up much beyond the boiler pressure, so that its proper working was interfered with.

Mr. ROBINSON said that some time ago an injector had been applied in the "Fox" gunboat, which worked with complete success; the sea water for the injector was conveyed to it through a pipe of considerable length, and of course there was a considerable variation of pressure in the supply according to the inclination of the vessel in the water; but notwithstanding this varying pressure he had not heard of a single instance of failure or difficulty. The former prejudice against the use of the injector for marine boilers arose he believed from an accidental mistake in first applying the injector on the "Great Eastern," where an injector of the size intended for feeding only one boiler was set to feed six, and had of course proved incompetent; the supply of water was not merely insufficient, but it was not

introduced into the injector in the proper mode, and air was admitted with it, and the injector was consequently stopped. For marine purposes however he was at a loss to understand why the injector should not work as well as on locomotives, or indeed a great deal better, inasmuch as it was more efficient for low pressures than high. One difficulty indeed, which might possibly arise in feeding marine boilers, was deposit of saline matter from the sea water in the various passages of the injector, which might choke up the nozzles after a length of time. At present however no difficulty of that kind had been met with; and an injector applied in a steamer running from Liverpool to Quebec had continued feeding the boiler during the whole of the outward voyage without any stoppage at all.

The CHAIRMAN proposed a vote of thanks to Mr. Robinson for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF A CURVILINEAR SHAPING MACHINE.

By Mr. FRANCIS W. WEBB, of Bolton.

This machine has been designed for the purpose of shaping the curved inner face of the rim of locomotive wheels between the spokes, so as to finish all portions of the rim to a true circle from the centre of the wheel, and leave the inner face of the rim parallel throughout to the turned outer face on which the tyre is bedded.

The machine is shown in Figs. 1 to 6, Plates 99 to 101. Fig. 1 is a plan of the machine; Fig. 2 a longitudinal section; and Figs. 5 and 6 are end elevations.

The wheel to be shaped, shown at A, Figs. 1 and 2, is mounted on a revolving table B on the bed of the machine; and a slow circular motion is given to the table by the ratchet-wheel and paul C on the worm shaft D, which works into the worm wheel on the table, as in an ordinary slotting machine. The table is moved forwards by the bed-screw E so as to bring the rim of the wheel under the

[redacted]

in the disc H. The disc being driven in the direction shown by the arrow, the tool has a quicker motion in the return stroke than in cutting.

On arriving at the junction of the rim with the spoke of the wheel, the rotation of the wheel is stopped by disconnecting the ratchet motion C; and by means of the worm-wheel and worm K Figs. 7 and 8, Plate 102, the tool F is turned slowly round in the lever G through a quarter circle, thereby rounding out the corner where the spoke joins the rim, as shown in Figs. 9 and 10. The tool is rotated either by a ratchet and paul on the worm shaft K, or by hand, the latter plan being found preferable in practice both for convenience and simplicity. The breadth of the toolholder is made exactly equal to the diameter of the circle to which the corner is to be rounded out; so that when the side of the toolholder comes up against the spoke of the wheel, as shown in Fig. 9, the tool is in the proper position for the feed motion C to be thrown out of gear, and the turning movement to be given to the tool by the worm wheel K.

As the radius of the curve at the corners of the spokes and rim is very small, the arm of the toolholder has to be kept out of the centre line of its shank. In the wheels for which the first machines were made, the radius of this curve was $\frac{3}{4}$ inch; and the front face of the toolholder was therefore made coincident with the centre line of the shank, and $1\frac{1}{2}$ inch wide, as shown in Figs. 7 and 8. With this arrangement the workman has no difficulty in fixing the tool with the proper amount of projection in the holder; for by winding the table round till the side of the toolholder touches the side of one of the spokes, as shown by the dotted lines in Fig. 9, and then turning the holder through a quarter circle, and fixing the tool so that its cutting edge just touches the side of the spoke, as shown dotted in Fig. 10, the tool is sure to be in the right position for shaping the rim of the wheel to the exact arc required, the whole adjustment being done with the greatest readiness.

The object of the writer in designing this machine was to bring the wheels of engines and tenders to a more correct balance, more

especially the carrying wheels, without at the same time increasing the cost of production; and the working of three of these machines at the Crewe Locomotive Works during the past twelve months has shown that a considerable saving is effected both in time and wages by this method of finishing a wrought-iron wheel forging, over the old plan of chipping and filing. A considerable saving is also effected in the smith's shop, as there is no necessity for planishing up the rims of the wheels; and by avoiding this planishing the rims can be left in the soft state, which the writer believes is preferable, rendering the wheel less liable to fail by fracture of the rim.

The writer's attention was more forcibly drawn to the subject of balancing the wheels, on occasion of examining a pair of leading wheels of an engine of the "Lady of the Lake" class on the London and North Western Railway, which had been reported as wearing the tyres very unequally. When the engine was examined, it was found that this unequal wear was not caused by any want of truth and squareness in the frame and axles; and the cause of the defect was then ascertained to be in the wheels themselves, which, though dressed on the inner face of the rim so as to look correct, were found on trial to be about 9 lbs. out of balance. After having been balanced, the same wheels were put to work again, and did not give any further trouble by unequal wear of the tyres.

Another case which occurred shortly afterwards was that of a [redacted]

would be fewer complaints of too quick running and bad roads; and at the same time a considerable saving in the wear and tear of tyres would be effected.

At Messrs. Sharp Stewart and Co.'s works in Manchester, where one of these machines is regularly at work, it is found that the cost in wages in the manufacture of wheels by the machine is about the same as by the old method of chipping and filing; but with two machines at work, as at the Crewe Works, the saving will be considerable, as one man can easily work both machines. The saving in files, which constitute one of the most considerable sources of expense in an engineering establishment, is also very great. It is found preferable for this slotting to be done dry, as the slight roughness thus left by the tool prevents the paint from being rubbed off; and with good steel there is no difficulty in completing the rim of a 5 feet or 6 feet wheel without once removing the tool for sharpening.

Mr. Webb exhibited the working arm of one of the shaping machines, which had been lent for the meeting by Messrs. Sharp Stewart and Co., showing the action in shaping the rim of a wrought-iron wheel.

The Chairman remarked that the mode of shaping the inner face of a wheel rim by the machine described in the paper was certainly a novel idea in the manufacture of railway wheels, and well deserving attention, as a means of finishing them by machinery more correctly than could be done by hand. He enquired what length of time was occupied with the machine in going all round the rim of a locomotive wheel of 5 feet diameter.

Mr. Webb replied that it would take about three hours to go round a wheel of that size, the machine requiring the attendance of one man; and the rim would then be finished to an exactly uniform thickness all round.

Mr. Robinson was convinced that the application of the machine described in the paper would rapidly extend, because it was well known that, as far as locomotive engine building was concerned, the use of tools was daily becoming more and more extended over every part of the work. In the case of all large forgings, the aim at the present time was to get them from the smith in large forged lumps, and then cut them down to shape in lathes and slotting machines, instead of employing smith's labour to work them down more closely in the first instance to the shape desired. In the forging of crank axles he remembered the time when as much as £7 was paid for smith's work in bringing the forging into shape ready for the lathe; but now the whole cost of shaping and finishing a crank axle was only from 40*s.* to 50*s.*, the smith never touching it at all after the forging of the original rough mass. This showed the great extent to which smith's work was now being superseded, and the expensive nature of that work was seen when it was considered that in addition to the smith's wages of 40*s.* per week each man required a couple of strikers to assist him, and a supply of coals for heating the work.

In the case of railway wheels an important portion of this cost of smith's work would be done away with by the application of the shaping machine now described. As the wheels were ordinarily constructed, the rim was welded up between each of the spokes, and in order to make it tolerably neat in appearance a considerable time was spent by the smith in planishing the inner curved surface of the rim, so as to bring it to the finished shape, while the outside of the rim was left rough to be afterwards turned in the lathe. By the application of the present machine however this additional labour was avoided, the inner face of the wheel rim being left rough by the smith, the same as the outside; and the smith's work was now confined to welding up the rim, leaving the whole of the finishing to be done by machinery. The result was of course a more mechanical job both in theory and in practice, avoiding those differences of thickness in the rim which were so detrimental to the steady running of the engines and the wear of the tyres. The application of the shaping machine to this purpose was therefore

unquestionably an important step in the right direction; and he thought the use of such a machine should not be confined to getting up the surface of railway wheels, as there were many other forms of iron work to which this curvilinear shaping movement might be advantageously applied.

Mr. WEBB mentioned that it had been suggested to make the inner surface of the rim flat instead of convex, so as to allow of shaping the wheel under an ordinary rectilinear slotting machine, without the necessity for a curvilinear motion of the tool; but the practical reason for making the inner face curved was that it would not be easy to ensure a sound weld with a flat surface, as the convex surface was required for enabling the hammers to strike well upon the inner face of the rim in the welding. The curvilinear movement in the shaping machine was therefore rendered necessary, in order to adhere to the curved shape of the face, and avoid cutting the iron to waste.

Mr. F. J. BRAMWELL remarked that, in the case of a railway wheel of 3 ft. 6 ins. diameter running at a speed of 50 miles an hour, each 1 lb. would have a centrifugal force of rather more than 90 lbs. or say $\frac{3}{4}$ cwt.; and therefore an amount of 9 lbs. out of balance, as mentioned in the paper, would cause a pressure on the bearing of about 7 cwts. in one direction, and then in 1-13th part of a second the same pressure in the opposite direction. It was only by taking into account the speed of revolution that the very serious effects could be appreciated of even so slight an error in balance.

Mr. WEBB observed that the value of perfect accuracy in balance of wheels running at a high speed was illustrated by the working of the traversing cranes at the Crewe Locomotive Works, in which the driving pulleys ran at a speed of 5000 feet per minute at the circumference, and had never given the slightest trouble since the cranes were first started in 1861, the pulleys having been each balanced very accurately in the first instance by trying them with the bearings on straight edges. In many cranes however, and other machinery employed in engineering workshops, there was no doubt that the wheels were not balanced as they ought to be; and much

trouble was consequently caused in keeping the whole in working order.

Mr. E. A. Cowper could confirm what had been said as to the importance of accurate balancing in machinery revolving at a high speed; for he remembered the case of a fan having arms of only a few pounds weight, where it was found that a strain of $2\frac{1}{2}$ tons was produced upon each arm in running at a high speed; and it was very surprising how much a small error in balancing would affect the revolution at high speeds. The employment of the machine now described for shaping the inside of the rim in railway wheels would certainly prove successful in establishing a perfect balance so far as the rim was concerned; and there remained only the spokes, in which any error of balance could exist, and he enquired whether any attempt had been made to finish the spokes by machinery in a similar manner. He had seen a machine employed for finishing the inner ends of the spokes at the boss, by slotting out the spaces between them with a round-nosed tool; but he did not know whether the body of the spokes was gauged with any degree of accuracy, though it was probable that the wheel was reasonably true in balance when the spokes had been forged in dies under the steam hammer. He concurred entirely in what had been said as to the importance of employing machinery instead of smith's labour for all work that could be done by machines; [redacted]

cutter carried in a rest bolted upon the rim of the wheel; this revolving cutter would then finish the heads of the spokes completely, and there would be no occasion to use the file at all.

Mr. Robinson considered that spokes forged in a die would not be found to require any subsequent dressing, but would be practically all uniform in size and therefore in correct balance, with as much truth as if they had been cast in a mould.

The Chairman moved a vote of thanks to Mr. Webb for his paper, which was passed.

The following paper was then read:—

ON AN IMPROVED TOOL AND HOLDER FOR TURNING AND PLANING.

By Mr. W. FORD SMITH, of Manchester.

The important part which Cutting Tools perform in all engineering and machine-making establishments, and the large numbers of them that are constantly used, render it of considerable importance that the most efficient and economical form should be adopted. The idea of making the cutting portion of the tool in a separate piece, fixed in a stem or holder, instead of both forming one piece as usual, has been previously carried out to a limited extent and with partial success; but practical difficulties seem to have prevented the general adoption of the plan.

Round steel cutters, held in lathe slide-rests specially arranged for the purpose, have been to some extent successfully employed for turning rollers of small diameter for cotton machinery, and for this purpose they answer admirably; but these cannot be used for turning large diameters nor for facing large flat surfaces, and

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Triangular steel cutters have been tried also with partial success; but the form of toolholder required for this section of steel precludes the possibility of sliding close up to a collar, for before the cutter itself can reach the collar the toolholder will come in contact with it or with any flange or flat surface, and will keep the cutting point from sliding up into the corner. Moreover this is practically a very expensive arrangement, as each triangular cutter requires to be nicely shaped and fitted into its holder; and if used for taking heavy cuts it is found difficult to prevent the cutter from being forced back into the holder: on these accounts the utility of triangular cutters is very limited.

The ordinary form of diamond-pointed tool, forged solid in one piece out of square bar steel, as shown in Fig. 1, Plate 103, is open to several objections. It is expensive to forge, particularly if made of the hooked form shown in the drawing. It requires to be ground both on the top and on the two sides; and the extent of these three surfaces renders the grinding expensive and complicated, especially if each surface is ground always to the correct angle. As the top surface becomes ground away, packing of different thicknesses is required to be placed under the stem of the tool, in order to raise the cutting part to the height of the lathe centres; and this causes waste of time. Also the tool will not turn both cylindrical and flat surfaces without its position in the slide-rest being altered. When the diamond-pointed tool is fed with a coarse traverse over the work, the surface produced is a series of ridges and furrows, as shown full size in Fig. 18, Plate 106; and the ridges require a considerable amount of hand labour to remove them, before a finished polished or scraped surface can be obtained.

In the improved Toolholder forming the subject of the present paper the cutting tool is separate from the holder, and is formed of a short piece of solid round steel, ground to the proper angle and fixed at the proper inclination in the toolholder, which is made of such a shape as to be applicable to all the principal descriptions of work. The toolholder is shown one quarter full size in Figs. 4 and 5, Plate 103; Fig. 4 represents one of the larger sizes,

and Fig. 5 a small size. Six different sizes are made, to suit the different sizes and classes of work, and for machines varying from large to small sizes.

The cutters A A are of the very best quality of steel that can be procured, and are made from bars of round steel cut into lengths with a cold set; each length is long enough to form two cutters, and is slotted through the centre while cold at the proper angle, as shown in Fig. 6, by a machine arranged for the purpose. The ends of a number of the cutters are then heated in a small furnace, and hardened in cold water. The toolholders B B are made of a strong and tough quality of steel, and after being forged nearly to the required shape are stamped while red-hot by a steam hammer in dies of the proper form. The upper and lower sides of the shank are planed parallel, to ensure its always bedding fairly and firmly in the toolboxes of the machines in which it is to be used; and the holder is then drilled for receiving the cutter, the hole being bored always at one standard angle, so as to give the correct angle of clearance to the cutter in every case, by means of a permanent inclined saddle upon the boring table, in which the holder is fixed.

The cutter is held in the toolholder by a steel set-screw C, shown half full size in Fig. 10, Plate 105, the end of which is recessed in the centre; and the portion of the cutter that it bears against is not hardened, so that the cutter is indented by the set-screw. The [redacted]

In the construction of these tools the angle that was found best for the clearance parts of the tools, Figs. 2 and 3, was adhered to as a standard in all cases, both for cutting cylindrical, taper, or flat surfaces in lathes, and for surfacing, down-cutting, or angling in planing machines; as any deviation from the best angle gives inferior results in cutting. The writer has found that an angle of 1 in 8 measured from the surface planed by the tool, as shown in Figs. 2 and 3, gives the best results. This inclination was accordingly adopted in the toolholder first made, for cutting surfaces at right angles to the shank of the toolholder, as shown in Fig. 3; and another holder was also made with the same angle of clearance on one of its sides, as shown in Fig. 2, instead of at the end, for cutting surfaces parallel to the side of the toolholder. Both of these however were superseded by the improved toolholder shown in Figs. 7 and 8, Plate 104, combining the two previous attempts in a single toolholder adapted to both purposes, having the angle of clearance both at the end and also at the side of the holder. The cutter is placed at the corner of the holder, so that the ground surface of the cutter is not square with either the side or the end of the holder, but midway between these two positions, at an angle of 45°, as shown in Fig. 7. It will be seen from the comparative diagram, Fig. 16, Plate 106, that the form of the new cutter closely corresponds with the most approved form of the cutting part in the best ordinary tools, the only difference being that the round cutter is made separate from the holder instead of being forged solid in one piece with it.

In Fig. 7, Plate 104, is shown at D a plan of the toolholder fixed on a slide-rest, with the tool in the act of turning the surface of a collar on a shaft, and thus cutting a flat surface. At E is shown the same holder still fixed in the same position on the slide-rest, but the tool is turning the cylindrical portion of the same shaft. The arrows show the direction of feed of the tool, at right angles to the shaft at D, and parallel with the shaft at E; but in both cases the most prominent round part of the cutter is seen to be fairly facing the metal, and the shavings escape at the same angle of 45° down the inclined ground surface of the cutter, so that the best effect is

produced in cutting. By this arrangement the tool is enabled to turn close up to collars and into corners, and to face the collars themselves and turn flat surfaces, or to do what is usually termed lathe surfacing, with the same toolholder and without moving its position in the slide-rest.

In turning cylindrical surfaces with the round cutting tools, it is of course requisite that the cutting point of the tool should be exactly on a level with the lathe centres, in order to produce a smooth turned surface. For this purpose a sheet-iron gauge of the simple form shown in Fig. 14, Plate 106, is supplied to each lathe, by means of which the tool is set up in the toolholder with complete accuracy to the exact height required; and the cutting edge being thus always level with the lathe centres, the turned cylindrical surface is finished as even and true as in planing a flat surface. As the tool is adjustable in the holder by the set-screw, it can be kept constantly at the proper height for cutting, without the necessity for inserting any packing under the toolholder in the toolbox of the lathe.

The toolholders are made in pairs, right-handed and left-handed, as shown in Figs. 12 and 13, Plate 105. Fig. 11 shows one fixed in the toolbox of a planing machine, planing the flat horizontal surface of a lathe bed; and the same toolholder is used for down-cutting vertical or angular surfaces. Fig. 13 shows it [redacted]

that the tools can be fed quickly over the work and thick heavy shavings of metal removed, while at the same time a smooth even and correctly finished surface is produced. When the tools are ground to the proper shape, they give clean curled shavings; but if badly ground tools are used, the cuttings are forcibly torn off, and the surface of the metal presents a pitted torn appearance. In such cases even with fine traverses the whole power of the machine is frequently absorbed with indifferent results, the cuttings being crumbled up into small fragments when thus pulled or torn off, while the tool occupies much more than the proper length of time in traversing over the work, and a rough uneven surface is produced, which requires a great amount of hand labour to finish it. In this way much more engine power is expended in proportion to the work done than is requisite if a correctly formed tool is used. If the tool is too acute or keen, it springs slightly in cutting, and does not cut evenly, but makes successive digs into the metal and produces a jarring effect. If the best formed tools of the ordinary construction are placed in the hands of an inferior workman and he is allowed to grind them for himself on an ordinary stone, he is tempted to grind only the extreme cutting points, which alone are blunted by use, in order to save himself some hard work; but by this means the tools are gradually altered from the properly acute cutting edges to very obtuse angles, which will not cut the metal but only tear it off. The full lines in the drawing, Fig. 1, give an idea of the incorrect form to which the tools are frequently ground in this way. The outer dotted line shows the proper form, with both the clearance and the cutting angles correct for cutting cast metals.

All risk of inaccuracy in grinding the round cutters is obviated by the use of the principle of mechanical grinding introduced by Mr. Whitworth; and Figs. 19 to 22, Plate 107, show the grindstone designed for this purpose by the writer, the tools being held against the face of the stone in a slide-rest F adjusted at the correct inclination. The rest is traversed backwards and forwards by the handwheel G across the face of the stone during the grinding; and by the second handwheel H the tool is held up against the stone with the required pressure. By this means the grinding of the tools at the correct angle for cutting is always ensured.

The employment of these simple cutting tools of round steel, separate from the toolholder, is attended with several practical advantages of importance. The form of the cutters is the simplest possible, being merely plain round bar steel, which can be rolled to the proper size in the first instance, so that no costly forging is required, nor any shaping or fitting; and the lengths to form the cutters are cut off the bars in the cold state, and are never heated except for the purpose of hardening the points. As they do not require to be hammered into form, there is no risk of the quality of the steel being injured by burning, as is sometimes the case with ordinary tools when the steel has been overheated by the smith for rendering it more easy to work. The higher qualities of steel are not only harder and more difficult to work, but they will less stand overheating, and are more liable to crack under the hammer.

Another advantage is that the repairing of tools is altogether dispensed with, as the round steel cutters can be worn down from long to short lengths, without requiring anything more than grinding and occasional hardening. Moreover the grinding is reduced to the simplest possible operation, as the end of the cutters alone is ground, and the sides do not require touching. Hence the proper section of cutter is never altered, however much the tools are ground; and the amount of grinding necessary to restore the proper cutting edge is reduced to a minimum, whereby the expense also is

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slide-rest being set at the required inclination to the face of the grindstone.

At the writer's works in Manchester, where these tools are in general use, it is found that on an average fifteen of the round steel cutters are blunted in one day's work by each machine; and they take about $\frac{1}{4}$ hour for re-grinding them, or an average of one minute each. With the improved toolholder, in order to avoid the delay occasioned with the ordinary tools by the men having to grind their own tools when blunted, leaving their machines standing idle during the interval, a day's supply of tools ready ground is given out to each machine in the morning, and the blunted tools are collected for grinding ready for the following day. The small size and weight of the round steel cutters allow of carrying out this plan in practice with complete facility; but with the heavy tools of the ordinary kind it would be impracticable to keep on hand the stock of tools requisite for such an arrangement. The weight of the day's supply of fifteen cutters is not more than two-thirds the weight of a single ordinary tool; and the toolholder itself is about the weight of one ordinary tool for the same class of work. There is thus a great saving in carrying the tools backwards and forwards from the machines to the grindstone, as the light detached cutters alone are required to be carried, while the toolholder itself is not moved; and as the grinding is all done by one man, it is not necessary that all the men should have to learn how to grind their own tools, and complete uniformity in the grinding is ensured.

The maximum depth of cut which any of the round cutters will take is one half its diameter; and the largest size of the round cutters being $1\frac{1}{4}$ inch diameter, if a cut of more than $\frac{5}{8}$ inch depth is required, a cutter is employed made of an oval section of steel, $1\frac{1}{4}$ inch deep by $\frac{5}{8}$ inch thick. This oval cutter is capable of taking a cut of 1 inch vertical depth in planing a horizontal surface; and in order that the cutter may not be forced back in the holder by the severe pressure of so deep a cut, the holder is in this case made with a solid bottom behind the cutter; as the cutter becomes worn down a few blanks

from a punching machine are placed under its end to fill up the bottom of the socket in the holder.

The quality of the work produced by the round steel cutters is found to be much superior to that obtained with the ordinary diamond-pointed tools, under the same circumstances as regards depth of cut and amount of feed, the finished surface produced by the round cutters being remarkably smooth, even when taking a heavy cut. The superiority of the round cutters in this respect arises from the difference of their action, as illustrated in the diagrams, Figs. 17 and 18, Plate 106, which show full size one of the round cutters and an ordinary diamond-pointed tool, the dotted lines indicating an equal amount of feed in both cases. Since the smoothness of the finished surface increases in proportion as the thickness of the shaving diminishes, the diamond-pointed tool in taking a heavy cut leaves the surface as rough at the bottom of the cut as at the top, since the shaving removed is of uniform thickness through its entire depth, as shown by the shaded portion K in Fig. 18. But with the round cutter the shaving is only thick at the top, as shown by the shaded portion J in Fig. 17, and the thickness gradually tapers away to almost nothing at the botttom, where the shaving becomes nearly a tangent to the circular cutting edge of the tool. Consequently although the surface left by the round cutter is as rough at the top of the cut as with the ordinary tool, this is of no importance, as that [redacted]

without soap and water. It will be seen that the round cutter has left a very fair finish for a rough dry cut, which contrasts favourably with the finish left by the ordinary diamond-pointed tool; also the minute ridges left between the successive cuts of the round tool are hardly perceptible, being only about one fifth of the height of the ridges left by the ordinary tool, as shown in the diagrams, Figs. 17 and 18.

This experiment served also to determine approximately the amount of power required to drive the round cutters, which is found to be only about three fourths of that necessary to drive the ordinary tools for doing the same work. The ordinary diamond-pointed tool employed in the experiment was shaped to the most approved form for cutting wrought iron; and the depth of cut being 3-16ths inch with a feed of 24 per inch, it was found that a weight of 74 lbs. was required, pulling direct upon the driving strap, to enable the tool to take the cut. After planing the width of $\frac{5}{8}$ inch, the round cutter, $\frac{3}{8}$ inch diameter, was substituted, going on from where the other had left off, and working under precisely the same circumstances; and the weight required upon the strap was only 56 lbs., or about three fourths of that required with the ordinary tool.

With regard to the saving effected in current expenses by the use of the improved toolholders and round cutters, it has been found at the writer's works that one smith and striker, who had been almost wholly employed in repairing and making the ordinary solid forged tools, are now dispensed with; and instead of two grindstones being always fully occupied in grinding the tools, the whole grinding of the cutters is now done by a single stone, requiring only one man for the purpose, instead of the time of the machine men being taken for grinding their own tools. Assuming therefore that the time of three men only is saved in grinding and repairing, at wages of only £1 each per week, this alone represents a saving of £150 per year; and this saving is independent of the increased quantity of work produced with the improved toolholders, in consequence of the machines being kept constantly running; while there is also the saving in engine power, and in finishing the work as it comes from the machines.

Mr. W. F. SMITH exhibited a number of the improved tools and toolholders, with specimens of work planed and turned by them, showing the character of the work done; and also specimens showing the amount of re-sharpening required by the tools after work.

The CHAIRMAN thought the improved plan of tools described in the paper had important practical advantages, and he was sure its introduction would be a subject of much interest to engineers, if from its simplicity and economy these advantages were realised.

Mr. E. A. COWPER thought the new plan of tools would prove very useful in engineering workshops, and would be particularly valuable in saving the loss of time at present involved in the grinding up of the tools, as it was most frequently the case that the machine was standing idle during the time of grinding. He enquired what was the quantity of work done in a day by the new tools in comparison with that got through by the ordinary tools when ground in a reasonable manner.

Mr. W. F. SMITH replied that he was not able to state the exact difference in the quantity of work produced; but that there was a decided advantage in this respect on the part of the new plan was shown by the fact that at his own works, although some of the piece-work prices had been considerably lowered since the new tools were introduced, the men were now making more wages than they ever [redacted]

hand, that were used in the new plan of tools, could be hardened to any extent, and when worn down to a short length it was only the cutter itself that had to be thrown aside and replaced, the toolholder remaining unaltered. The greatest practical difficulty however which he had experienced with the ordinary tools was to get the men to grind them to the correct angle, each man having his own idea as to the best cutting edge; and it was therefore a great advantage in the new plan of tools that the men would not grind their own tools, and that the construction ensured the whole of the tools being correctly ground to the proper angle.

Mr. J. B. Fenby enquired whether any difficulty had been found from the toolholder springing, and thereby causing the tool to dig into the work in turning and planing. In the case of turning, he suggested that this might be obviated by placing the cutting edge of the tool just below the level of the neutral axis of the stem of the toolholder, instead of above it, so that the tendency of the tool would be to clear itself if there were any springing of the holder; and similarly in reference to planing. He noticed also that in the arrangement shown for grinding the tools the grindstone was represented as turning from the tool, which was generally considered to produce a ragged edge on the tool very soon; but by making the grindstone revolve in the opposite direction towards the tool, a much smoother and firmer edge was produced, and he had found that tools ground in this way would last half as long again as if ground on a stone revolving from the tool.

Mr. W. F. Smith replied that the digging in of the tool was simply a question of the angle of the tool and the position of the slide rest. If the cutting edge of the tool were made too acute, it was sure to dig into the work, provided the cut was heavy enough; but by taking care to keep the cutting edge of the tool exactly level with the centre line of the work in the lathe, and by having the tools all ground correctly to the proper angle, he had found there was no risk of any such occurrence. With respect to the direction of revolution of the grindstone for grinding the tools, it appeared to him to be quite immaterial whether the stone turned one way or the other. In grinding with the stone revolving from the tool, as

shown in the drawing, a mere thin film was found to be left on the edge of the tool after grinding, which was taken off by rubbing the tool on the stone by hand. The principal object in grinding the cutters in this way instead of the other was to make the stone available also for grinding tools by hand on an ordinary hand-rest placed on the opposite side of the stone to the slide-rest.

Mr. WEBB remarked that in taking heavy cuts in hard metal it was always found advisable to make use of a large tool for the purpose, in order to carry away the heat from the point of the tool; and in this respect therefore a small tool, such as the round cutter in the new tools, seemed undesirable for that class of work. Another objection to a small tool was that it had not stiffness enough for a very heavy cut.

Mr. W. F. SMITH explained that with the new tools it was not intended to take a deep cut with a small diameter of tool, and the depth of cut ought not to be more than about half the diameter of the tool, when the tool was made of round steel. For a deep cut an oval tool was employed, as shown by the specimen exhibited, which was suitable for a cut 7-8ths inch deep; and with this depth of cut the tool would take about ten cuts per inch of feed.

Mr. ROBINSON considered it was very important to put a stop to the great waste of steel which at present took place with the ordinary tools, both in originally forging them to the required shape [redacted]

and the correct angle for the front of the tool was tested by placing the tool upon the flat surface and bringing it up against the cone. With the round cutters he thought that a still further improvement might be made for finishing the work, by using a tool having a small portion of its cutting edge straight, by making the cylindrical tool with a flat surface throughout on one side, so as to remove the slightest trace of ridges on the finished surface of the work; just as with the ordinary angular tools at present in use the workman in taking a finishing cut would grind off the extreme point of the tool, and so leave a straight part between the two inclined edges. The mode of grinding the tools, with the grindstone revolving from the tool, as shown in the drawing, would have the effect he thought of giving a ragged edge to the tool, and it appeared preferable therefore to run the stone in the opposite direction, as in grinding the edges of the ordinary cutting tools. The new plan of tools was certainly admirably worked out, and appeared well calculated not only for saving cost but also for improving the quality of the work done.

Mr. W. F. Smith said that on the first introduction of the round cutters he had found the men flattening the cutting edge for the finishing cut, under the idea that this was necessary for preventing ridges on the work; but this was not allowed now, as any flattening of the cutting edge did away with the peculiar advantage of the round tool in accuracy of the cutting angle, the amount of flattening being altogether a matter of uncertainty, dependent on the judgment of each separate workman. Theoretically there was of course inevitably a slight ridge left between the successive cuts of a round tool traversing along the work; but in practice, when the rate of feed was properly proportioned to the diameter of the cutter, these ridges were so exceedingly minute as to be altogether inappreciable, and the result was a practically smooth surface, quite as smooth as that produced with the best of the ordinary tools.

The Chairman enquired whether the round cutters were found applicable to all descriptions of machine work.

Mr. W. F. Smith replied that the round tools were found by experience to be equally applicable for all descriptions of straight

work, such as planing and turning, and partly also for slotting; but for drilling and boring machines they were of course not suitable. In special cases of turning out sharp corners where a square corner was particularly desired, it would of course be necessary after using a round tool to substitute one of the ordinary diamond-pointed or square tools to reach into the corner, as the round tool left all corners rounded out to a circle of its own diameter.

Mr. F. J. Bramwell thought the round tool had a decided advantage for turning collars on shafts, because it was then impossible for the workman to spoil the work by cutting out the corners square, as was too frequently done; but with the round tool he would be compelled to leave them all nicely rounded out.

The Chairman enquired what were the two angles in the standard gauge employed for giving the inclination of the round cutters.

Mr. W. F. Smith replied that the angles of the gauge were 50° for wrought iron, and 60° for cast iron and brass, which were the angles that he had found the best for the different descriptions of metal.

The Chairman proposed a vote of thanks to Mr. Smith for his paper, which was passed.

Fig. 1. Vertical Section of Governor for Clocks, &c. Scale half full size.

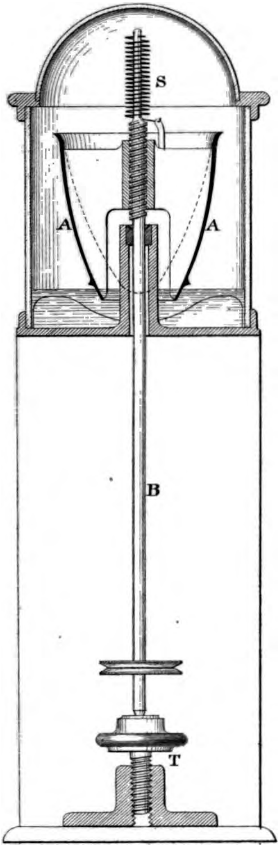


Fig. 2.

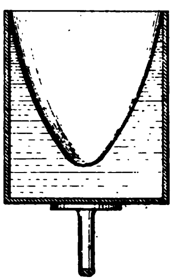
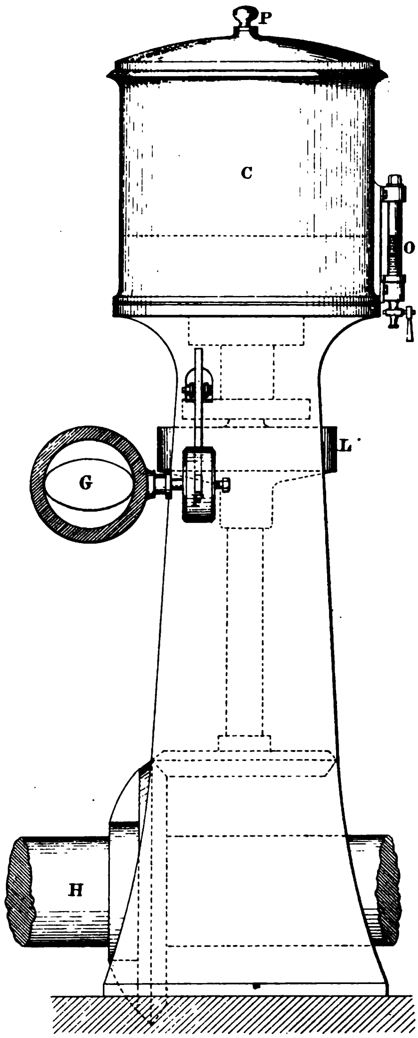
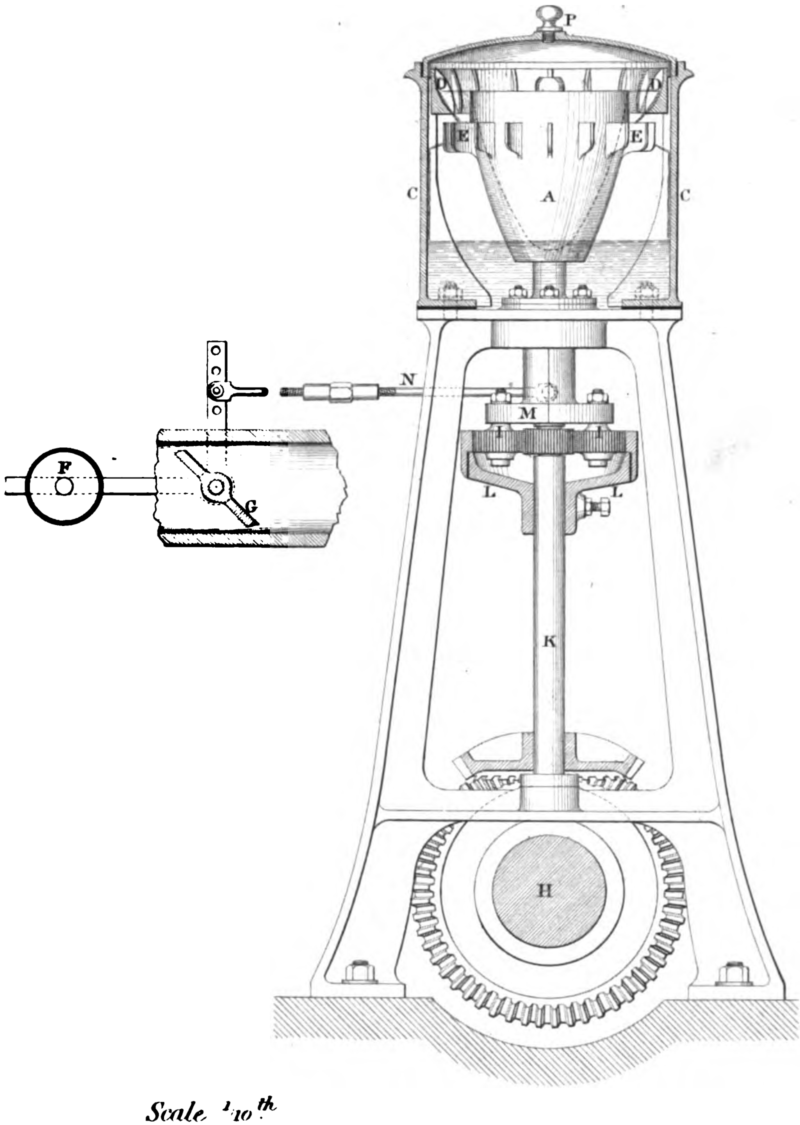


Fig. 3. Side Elevation of Steam-Engine Governor.



Scale 1/10th

Fig. 4. Vertical Section of Steam-Engine Governor.

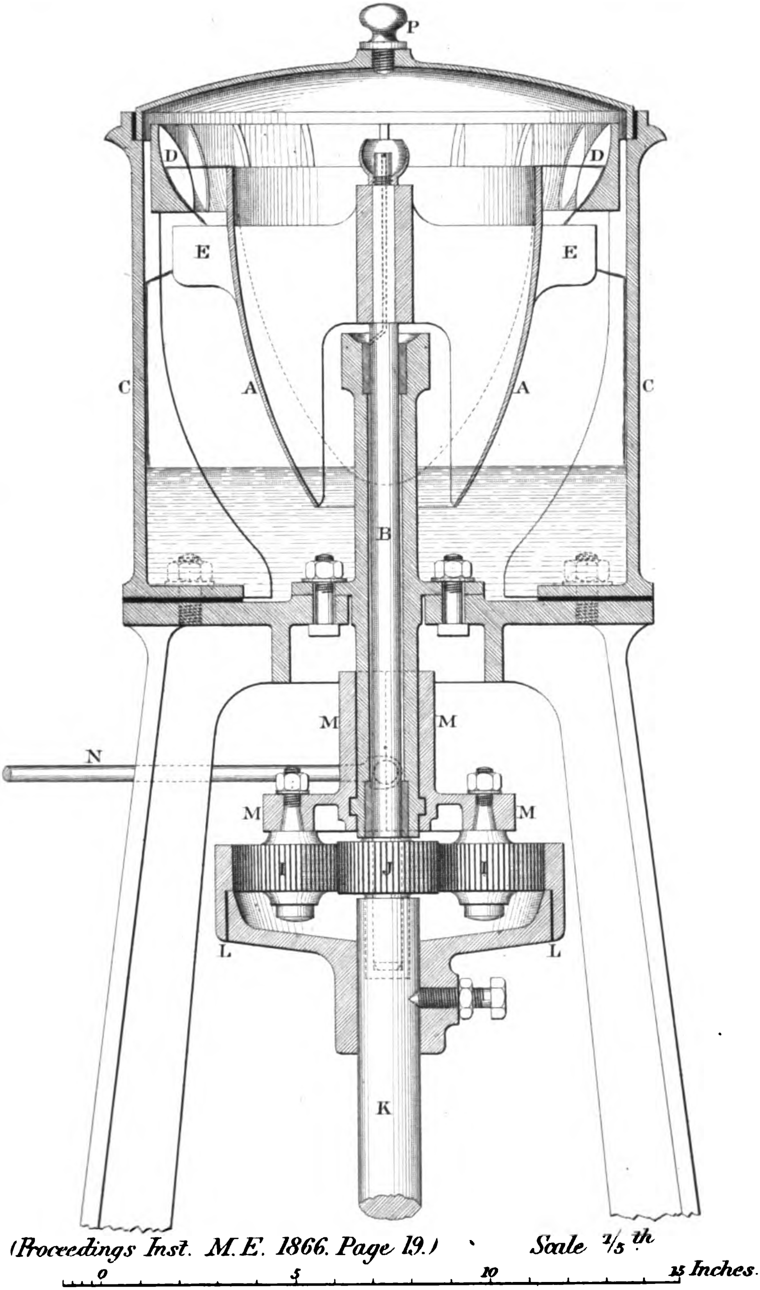


Scale 1/10th

0 10 20 30 *Inches.*

(Proceedings Inst. M. E. 1866. Page 19.)

Fig. 5. *Vertical Section of Steam-Engine Governor, enlarged.*



(Proceedings Inst. M.E. 1866. Page 19.) *Scale 1/5 th*

Steam-Engine Governor.

Fig. 6. *Sectional Plan of Revolving Cup.*

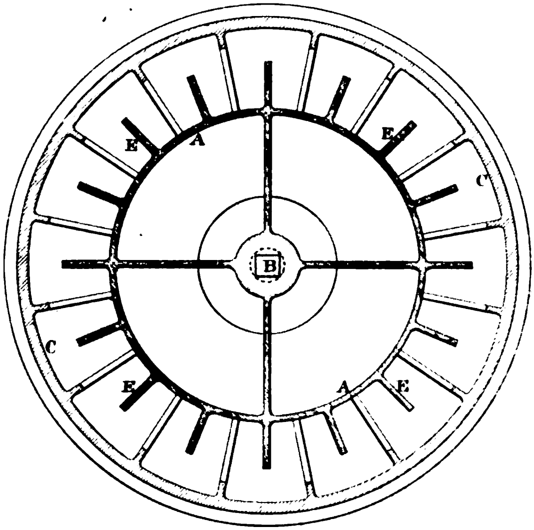
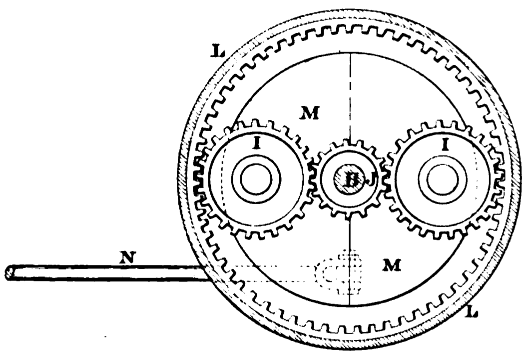


Fig. 7. *Inverted Plan of Differential Wheels.*



(Proceedings Inst. M.E. 1866. Page 19.) *Scale 1/5 th*

0 5 10 15 Inch

WROUGHT IRON TURNTABLE. *Plate 5.*

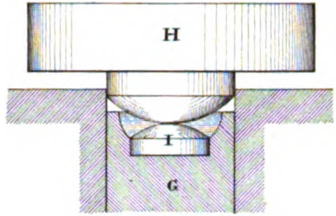
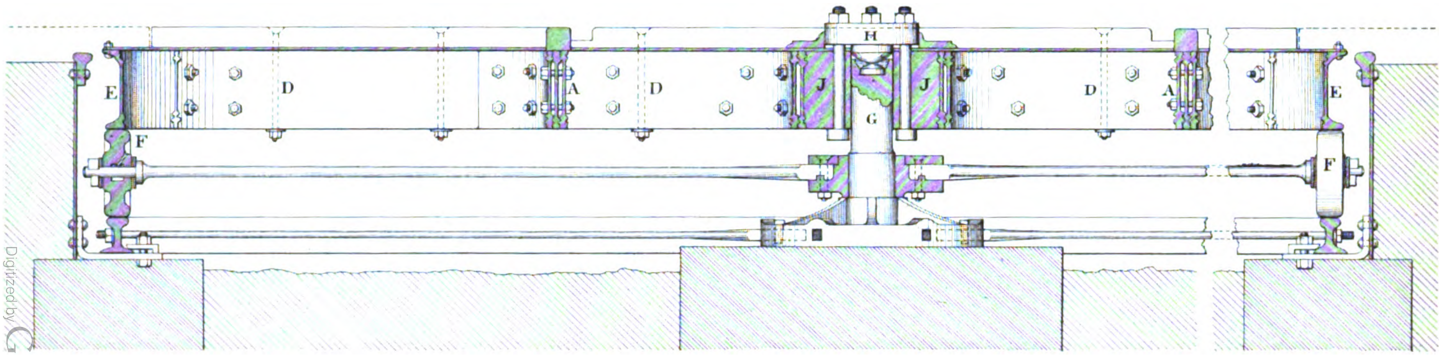


Fig. 2. *Cast Iron Centre Bearing. Scale 1/6th.*

Fig. 1. *Vertical Section of 12 foot Turntable.*

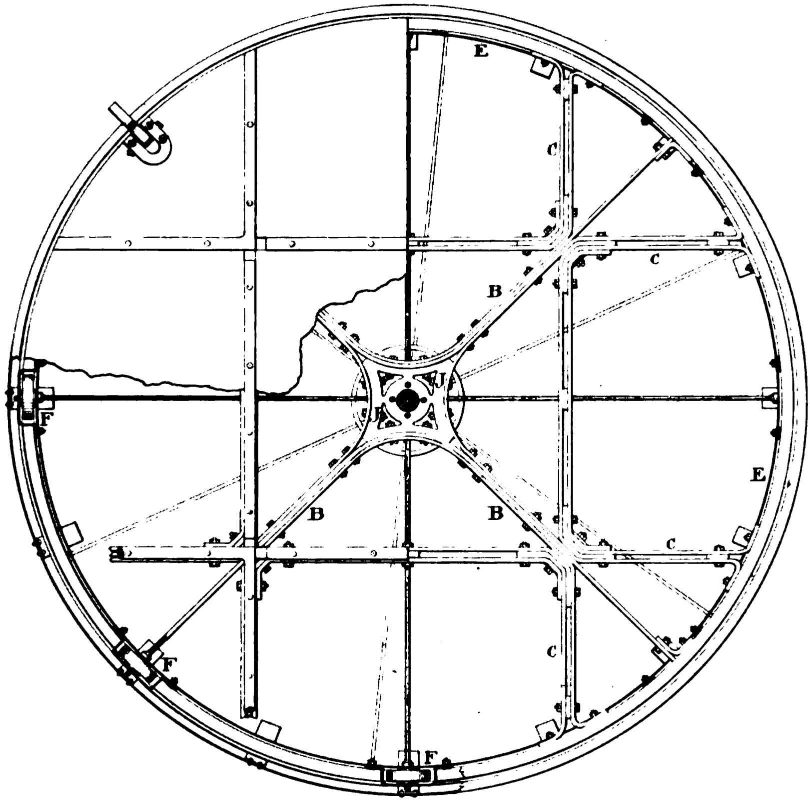


(Proceedings Inst. M.E. 1866. Page 43.)

Scale 1/18th.

Ins. 12 6 0 1 2 3 4 5 6 7 8 Feet.

Fig. 3. *Plan of 12 foot Turntable.*

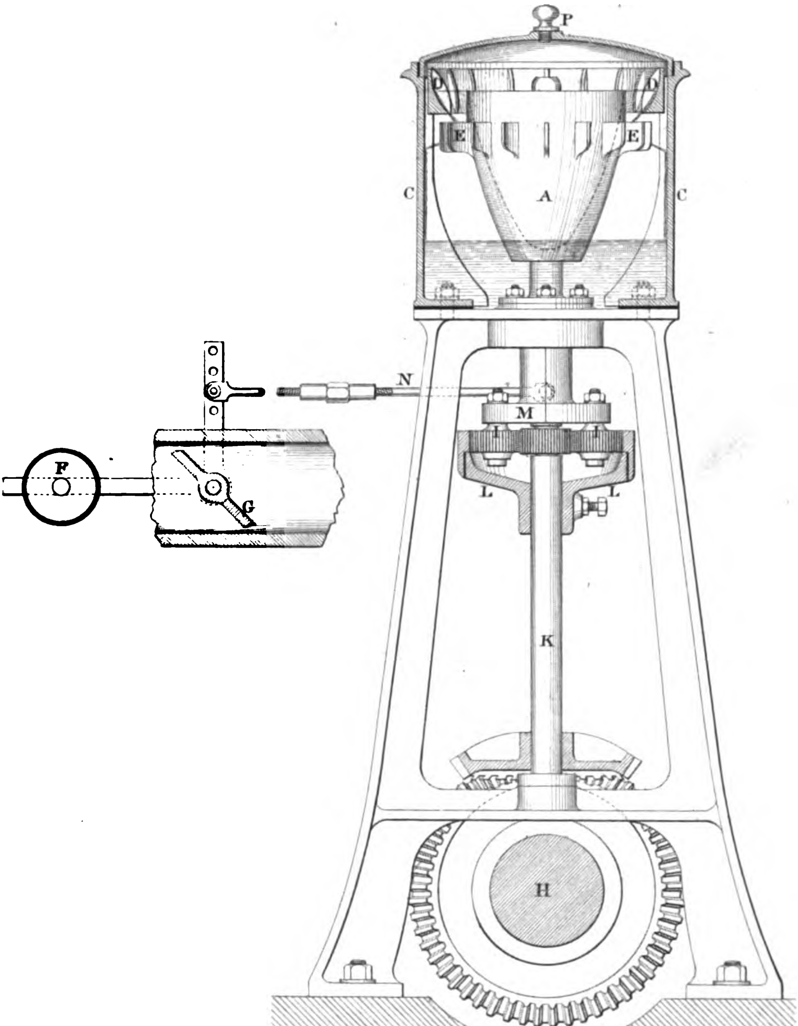


Scale 1/36th

0	1	2	3	4	5	6	7	8	9	10 Feet.

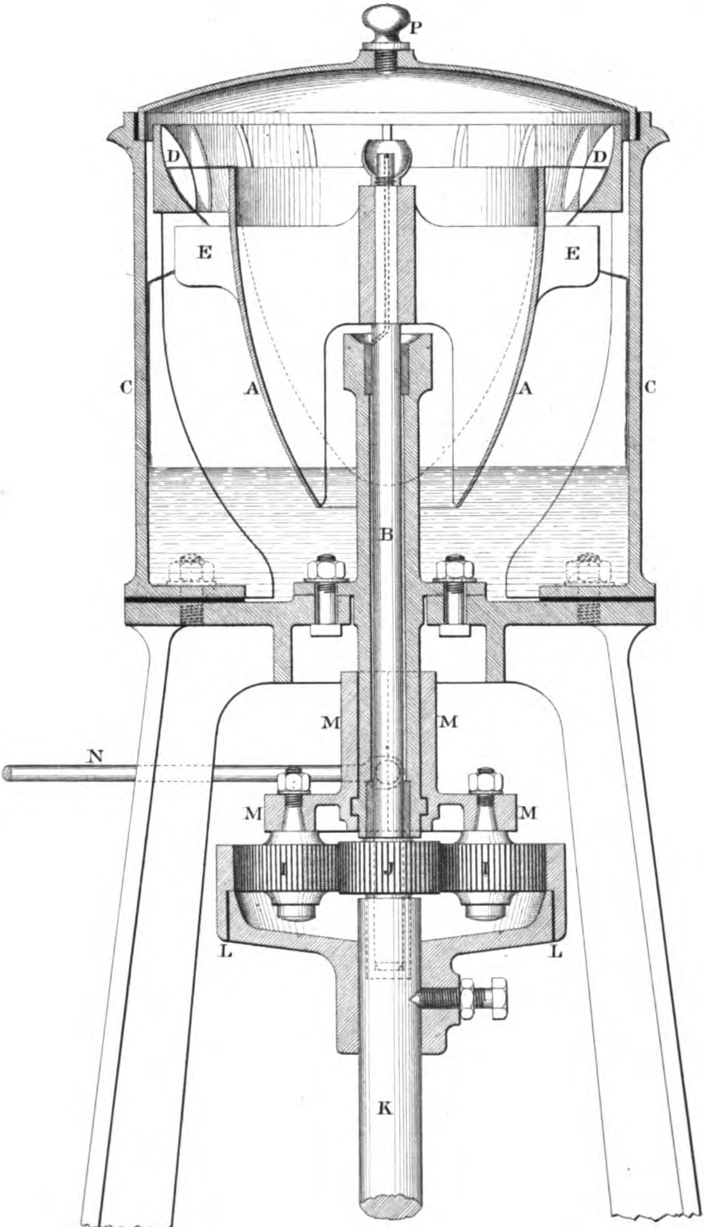
(Proceedings Inst M.E 1866. Page 43.)

Fig. 4. *Vertical Section of Steam-Engine Governor.*



Scale 1/10th.

Fig. 5. *Vertical Section of Steam-Engine Governor, enlarged.*



(Proceedings Inst. M.E. 1866. Page 19.) *Scale 2/5th*

0 5 10 15 *Inches.*

Steam-Engine Governor.

Fig. 6. *Sectional Plan of Revolving Cup.*

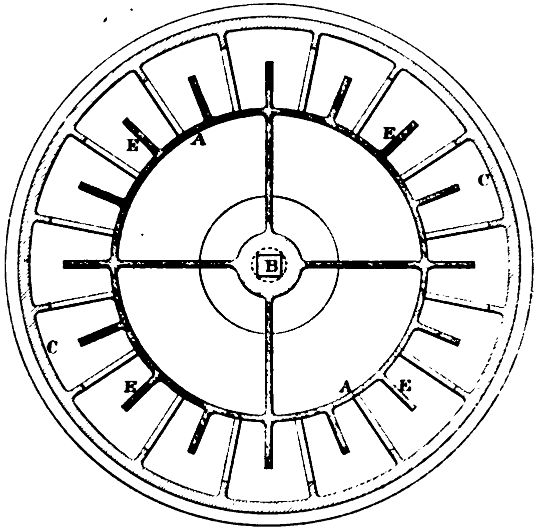
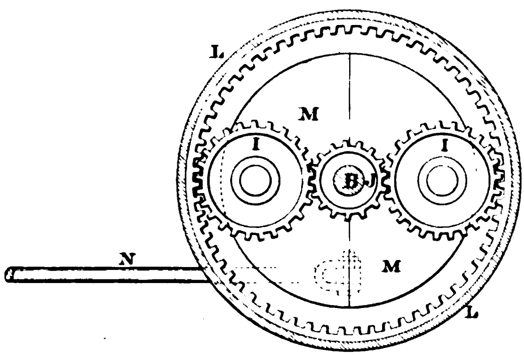


Fig. 7. *Inverted Plan of Differential Wheels.*



(Proceedings Inst. M. E. 1866. Page 19.) *Scale* 1/5 th

WROUGHT IRON TURNTABLE.

Plate 5.

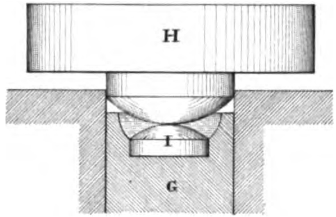


Fig. 2. *Cast Iron Centre Bearing.* *Scale 1/6th.*

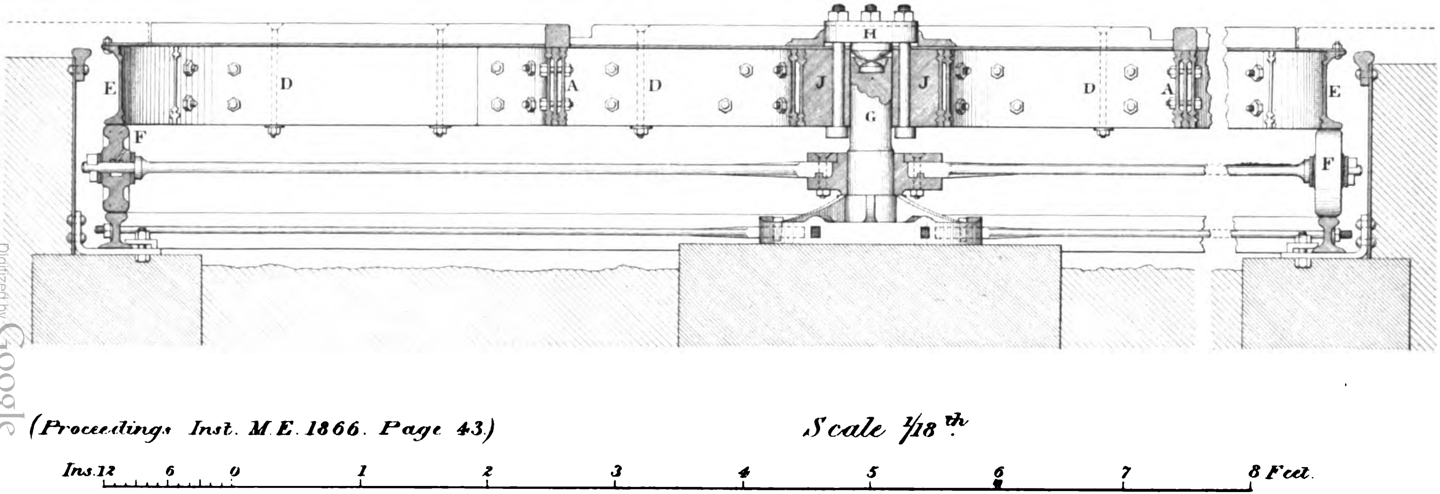
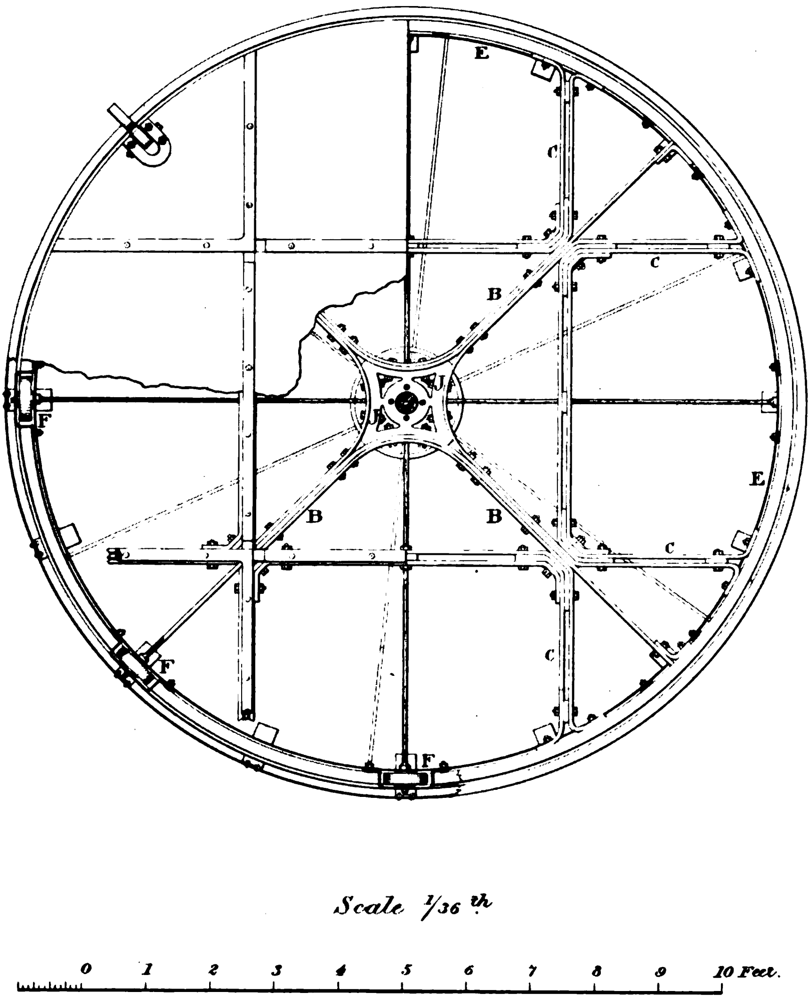


Fig. 1. *Vertical Section of 12 foot Turntable.*

Scale 1/18th.

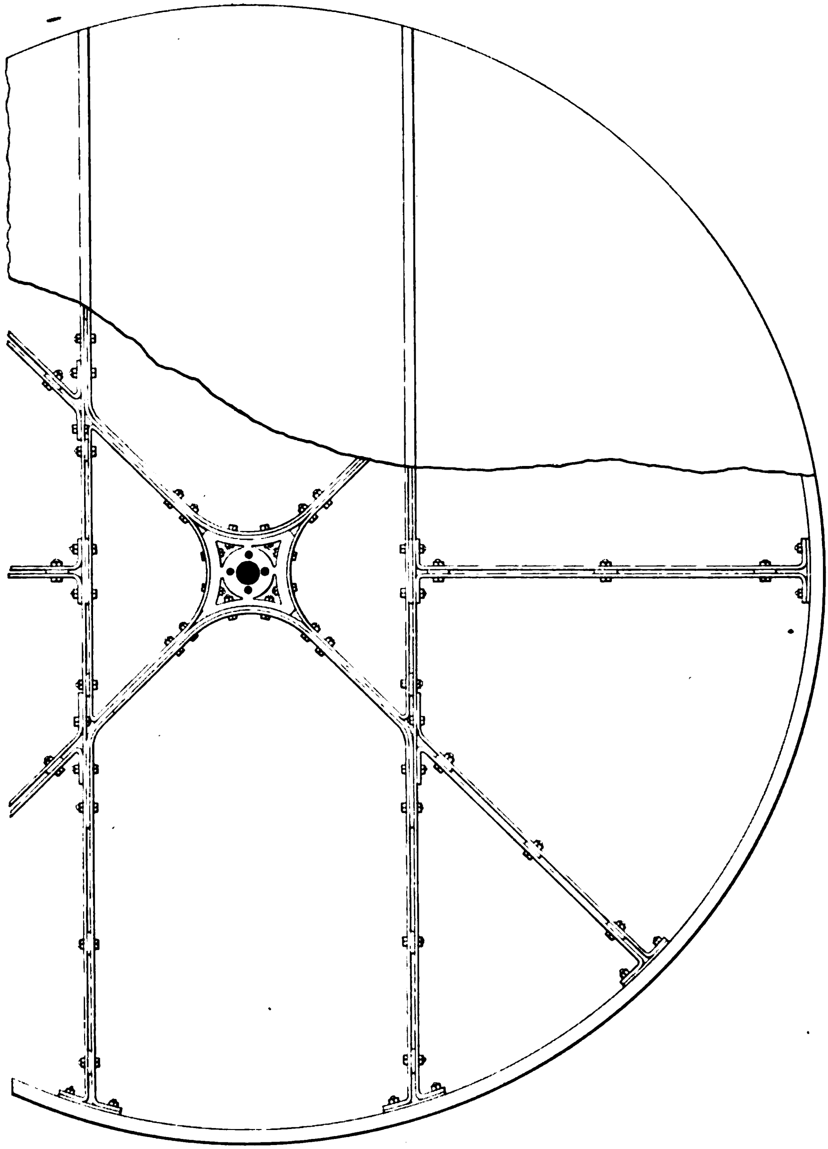
(Proceedings Inst. M.E. 1866. Page 43.)

Fig. 3. *Plan of 12 foot Turntable.*



(Proceedings Inst M. E. 1866. Page 43.)

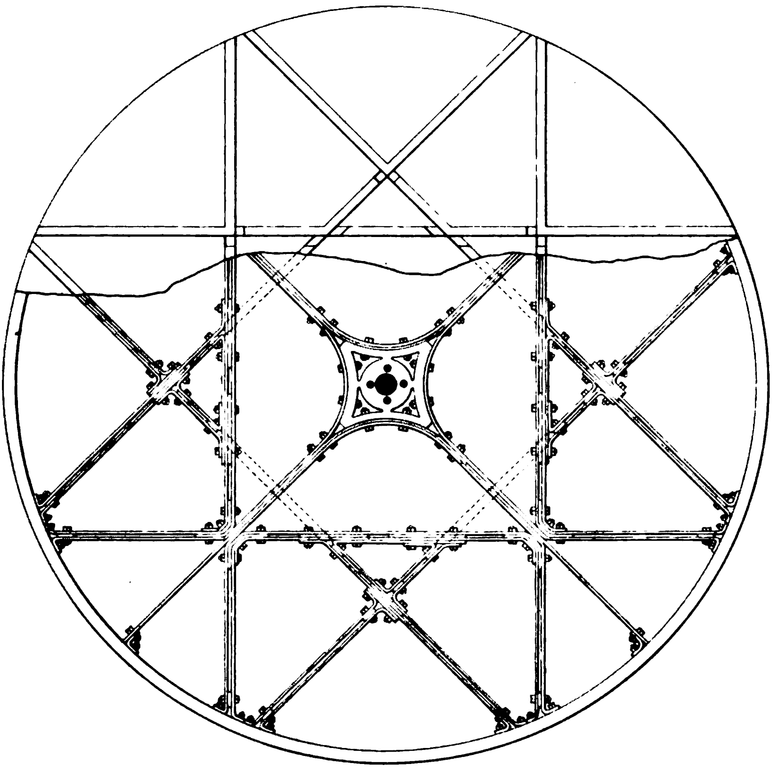
Fig. 4. *Plan of 18 foot Turntable.*



(Proceedings Inst. M.E. 1866. Page 43.) *Scale 1/36th.*

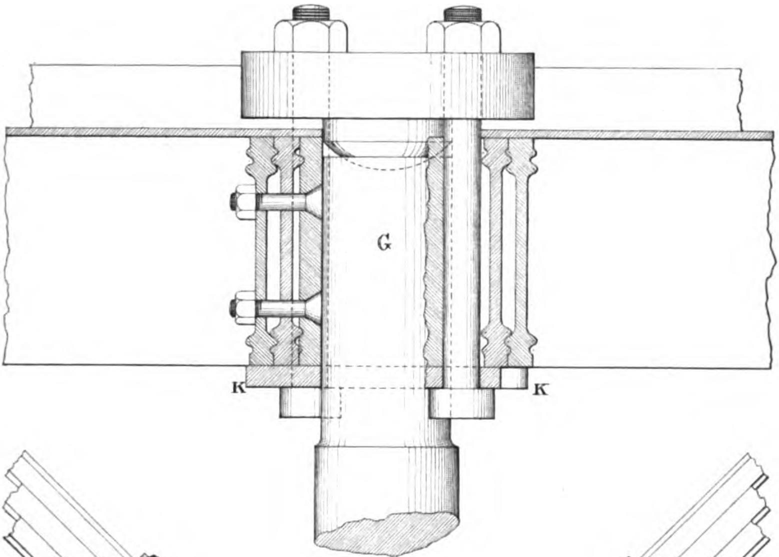
0 1 2 3 4 5 6 7 8 9 10 Feet.

Fig. 5. *Plan of Four-Line Turntable.*



Scale 1/36th.

Fig. 6. *Vertical Section of Wrought Iron Centre.*



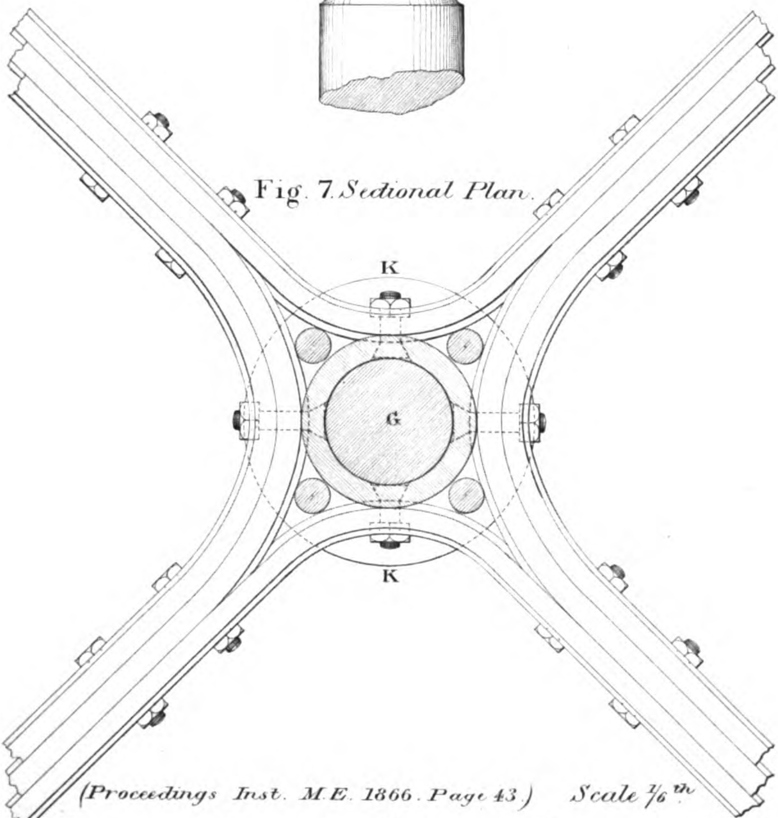


Fig. 7. *Sectional Plan.*

(Proceedings Inst. M.E. 1866. Page 43.) *Scale 1/6th*

0 5 10 15 20 *Inches.*

Plate 10.

WROUGHT IRON TURNTABLE.

Fig. 8. Section of Single Bar of Turntable.

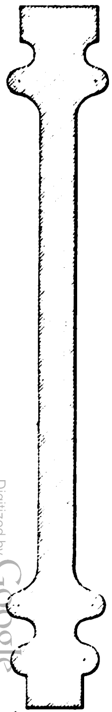


Fig. 9. Section of Compound Girder of Turntable.

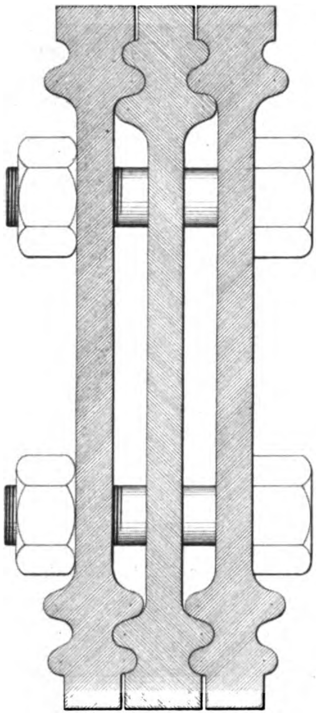


Fig. 10. Section of Rim of Turntable.

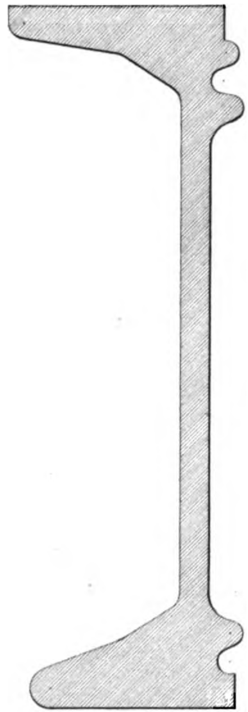
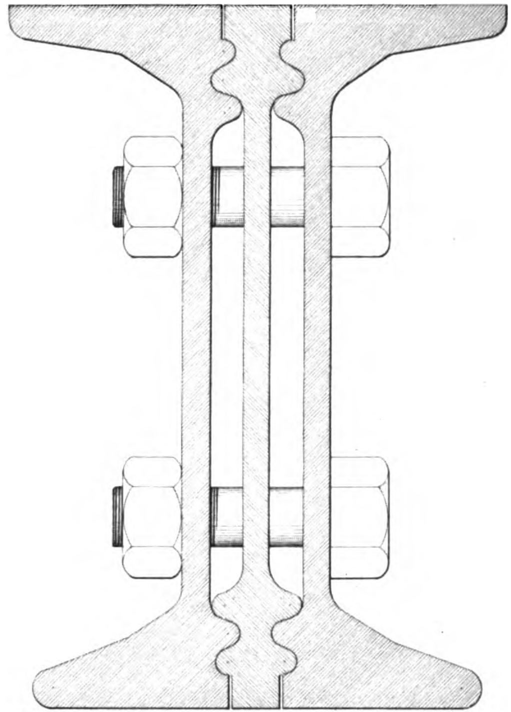


Fig. 11. Girder formed of two Rims with intermediate Single Bar.



(Proceedings Inst. M.E. 1866. Page 43.)

Scale half full size.

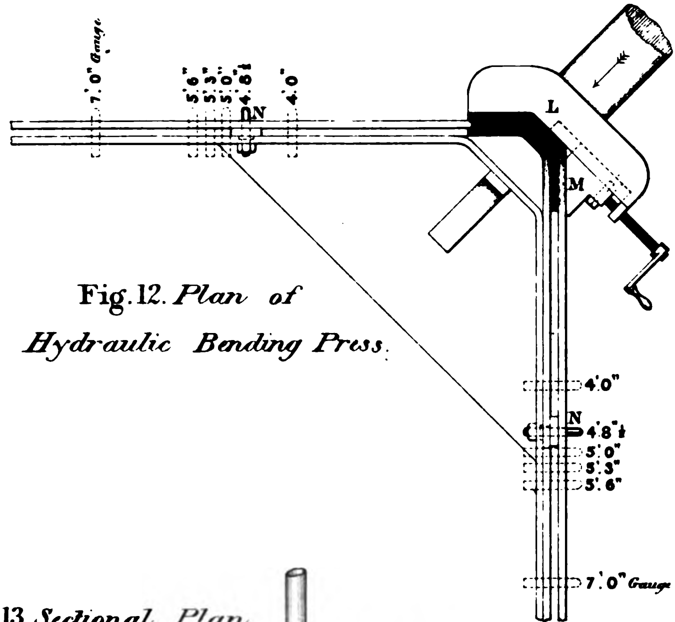


Fig. 12. *Plan of Hydraulic Bending Press.*

Fig. 13. *Sectional Plan of Portable Forge for Bending Ends of Bars.*

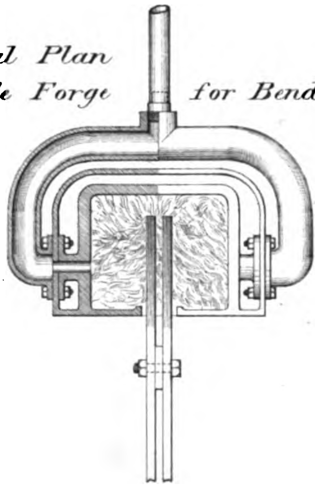
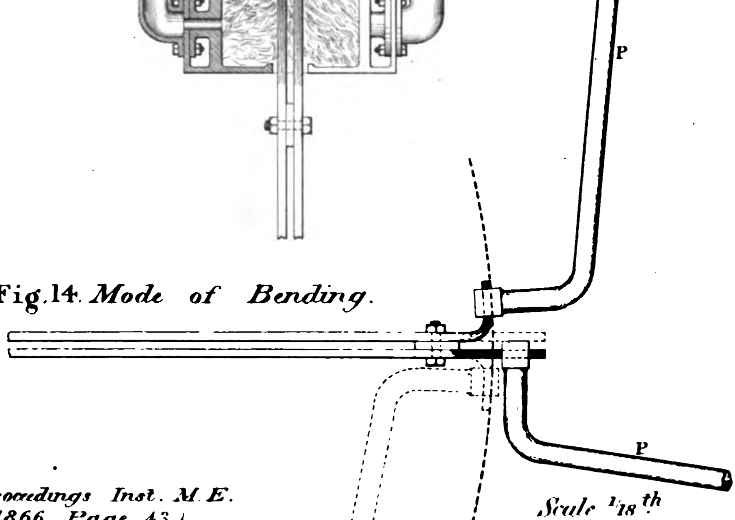


Fig. 14. *Mode of Bending.*



(Proceedings Inst. M. E. 1866. Page 43.)

Scale 1/18th

Ins. 12 6 0 1 2 3 4 Feet

CORRODION OF LOCOMOTIVE BOILERS. *Plate 12.*

Diagrams showing Grooving caused by Corrosion in ordinary Boiler Barrels with Angle-Iron and Lap Joints.

Grooving at Angle-Iron Joints at Smokebox and Firebox ends.

Fig. 1. *Plan of Inside of Boiler Plate at Smokebox end.*

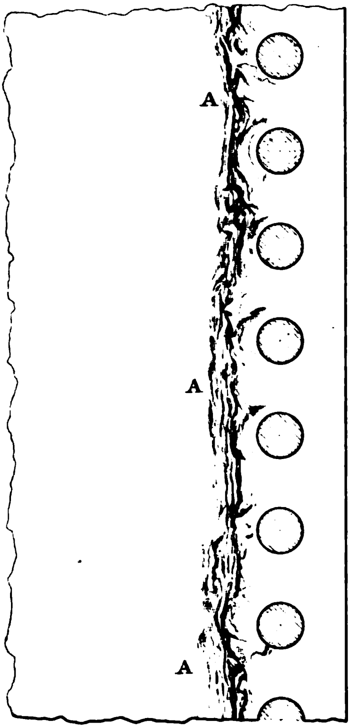
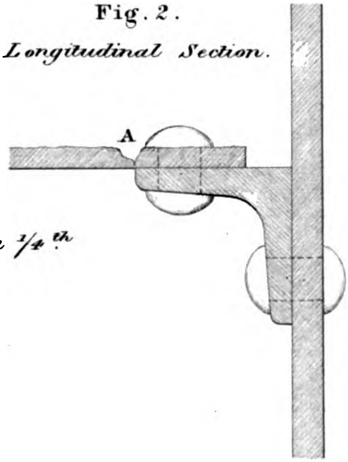


Fig. 2.
Longitudinal Section.



Scale 1/4th.

Fig. 3.
Full size Section of Grooving at **A.**

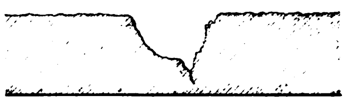
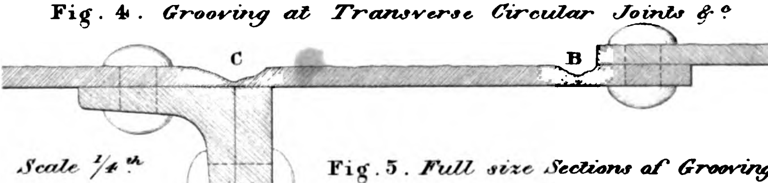
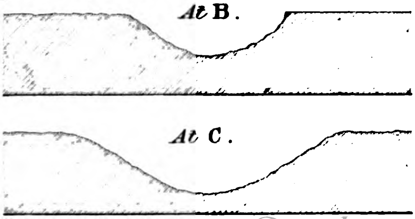


Fig. 4. *Grooving at Transverse Circular Joints &c.*



Scale 1/4th.

Fig. 5. *Full size Sections of Grooving.*



CORROSION OF LOCOMOTIVE BOILERS. *Plate 13.*

Diagrams showing Grooving caused by Corrosion in ordinary Boiler Barrels with Lap Joints.

Fig. 6. *Grooving at Longitudinal Joints.*

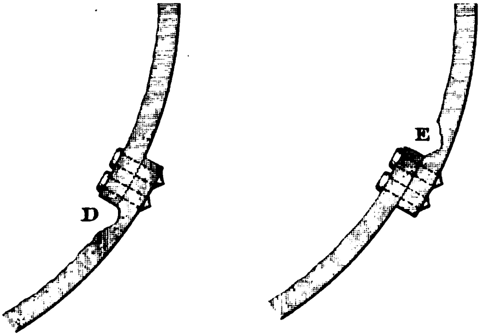
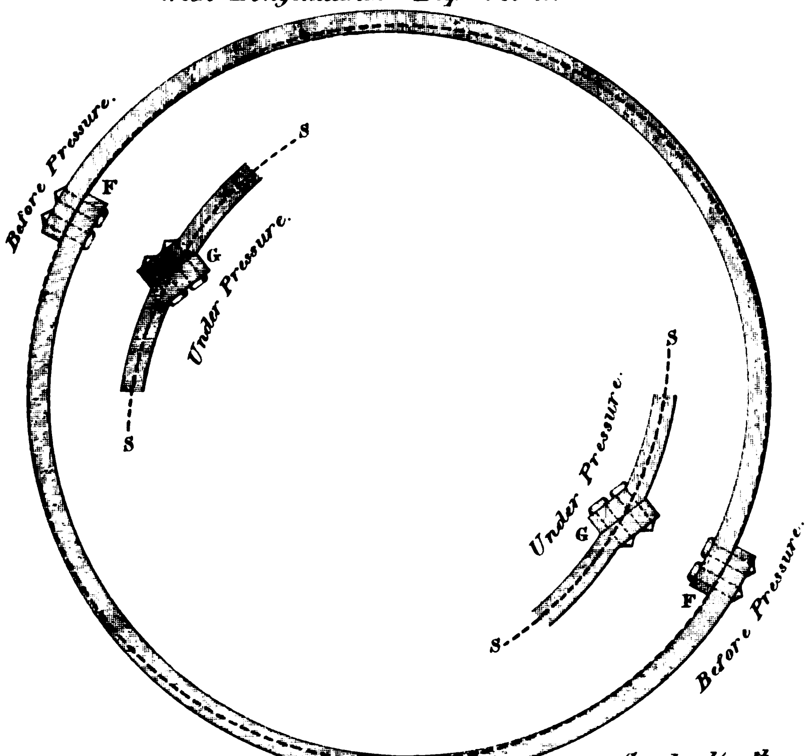


Fig. 7. *Transverse Section of Ordinary Boiler Barrel with Longitudinal Lap Joints.*



Scale 1/12th

Thickness of Plates magnified 3 times.

CORROSION OF LOCOMOTIVE BOILERS.

Plate 14.

Diagrams showing line of Longitudinal Strain in Boiler Barrel, before pressure and under pressure.

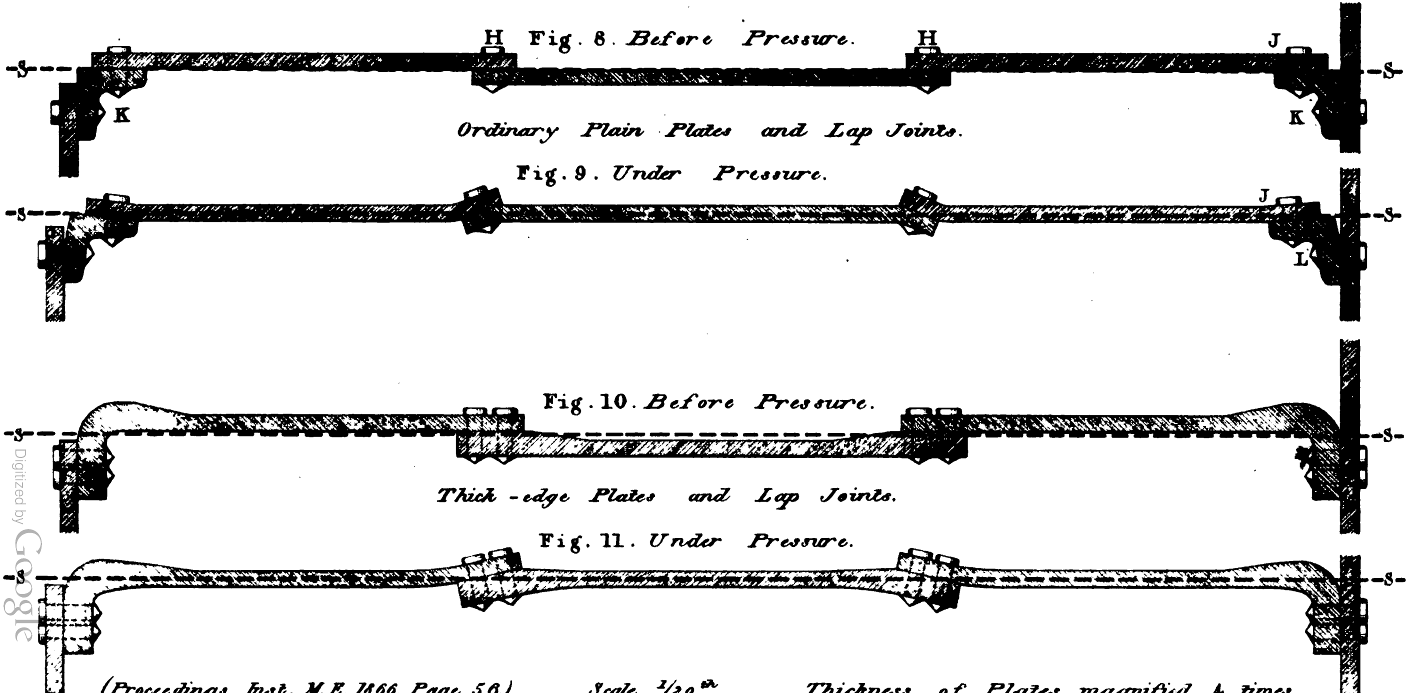


Fig. 8. *Before Pressure.*

Ordinary Plain Plates and Lap Joints.

Fig. 9. *Under Pressure.*

Fig. 10. *Before Pressure.*

Thick-edge Plates and Lap Joints.

Fig. 11. *Under Pressure.*

(Proceedings Inst. M.E. 1866. Page 56.) *Scale 1/20th.* *Thickness of Plates magnified 4 times.*

CORROSION OF LOCOMOTIVE BOILERS. *Plate 15.*

Diagrams showing line of Longitudinal Strain in Boiler Barrel, before pressure and under pressure.

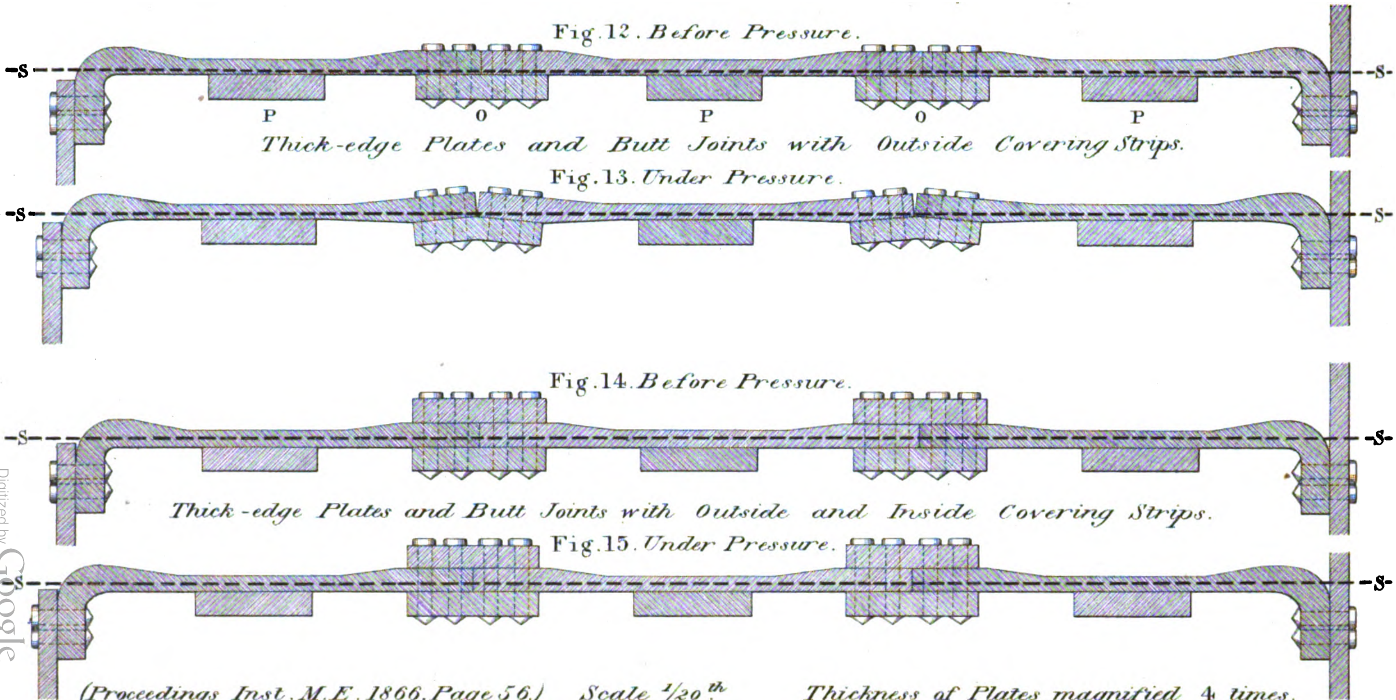


Fig. 12. *Before Pressure.*

Thick-edge Plates and Butt Joints with Outside Covering Strips.

Fig. 13. *Under Pressure.*

Fig. 14. *Before Pressure.*

Thick-edge Plates and Butt Joints with Outside and Inside Covering Strips.

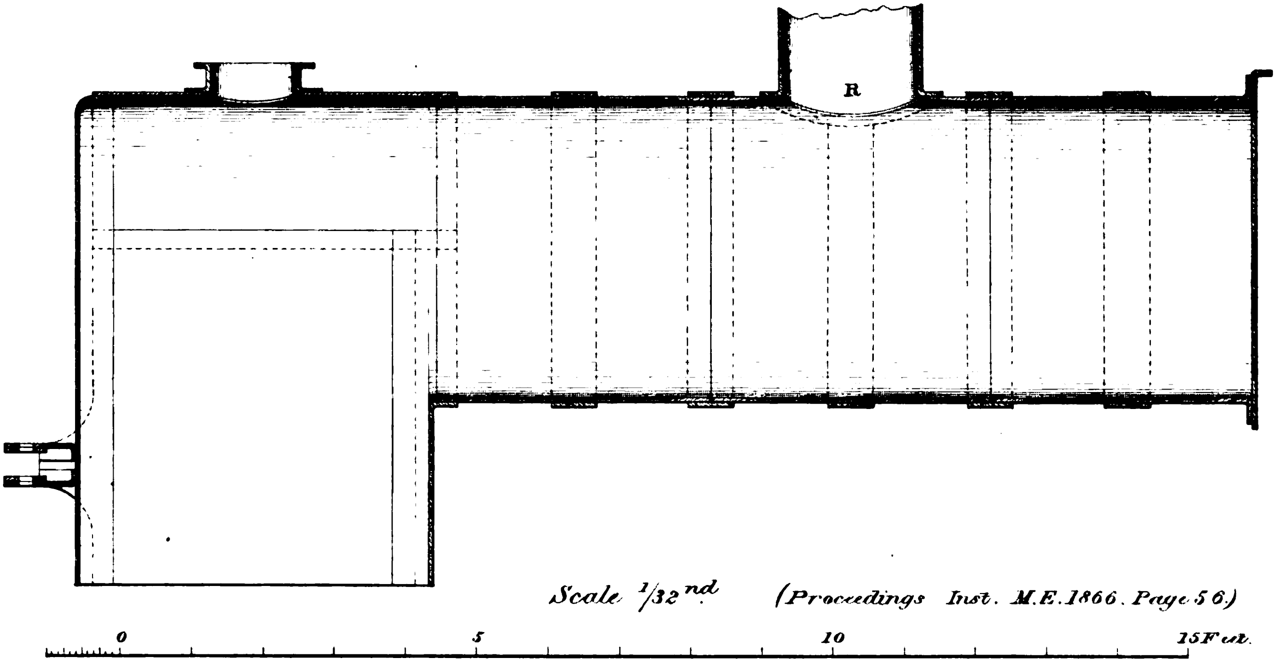
Fig. 15. *Under Pressure.*

(Proceedings Inst. M.E. 1866. Page 56.) *Scale 1/20th* *Thickness of Plates magnified 4 times.*

CORROSION OF LOCOMOTIVE BOILERS.

WELDED BOILER WITH THICK-EDGE PLATES AND BUTT JOINTS.

Fig. 16. *Longitudinal Section.*



Scale 1/32nd. *(Proceedings Inst. M.E. 1866. Page 56.)*

CORROSION OF LOCOMOTIVE BOILERS.

WELDED BOILER WITH THICK-EDGE PLATES AND BUTT JOINTS.

Fig. 17. *Sectional Plan. Scale 1/32nd.*

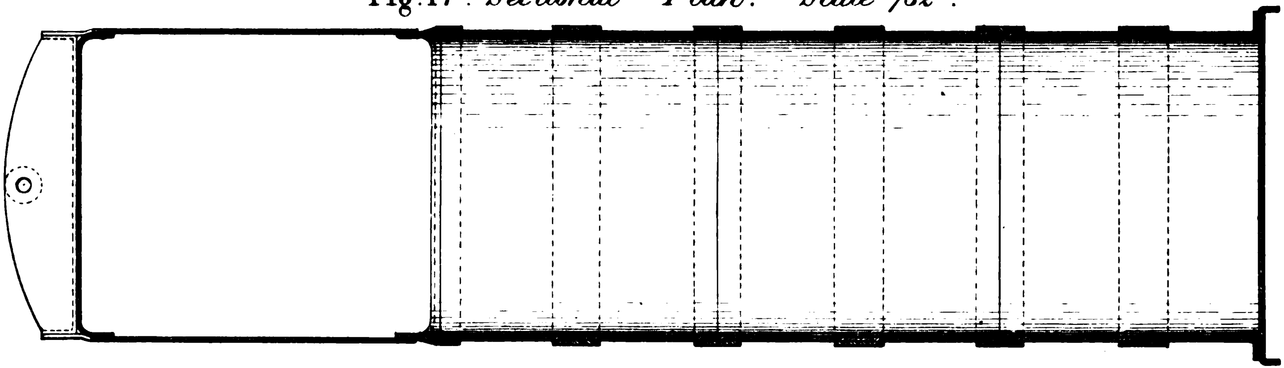
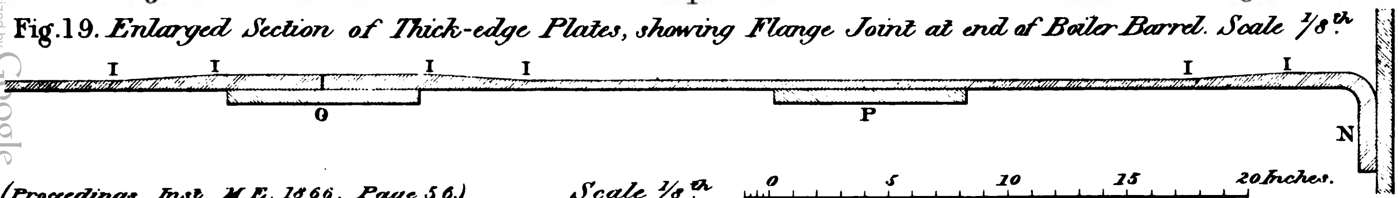


Fig. 18. *Enlarged Section of Thick-edge Plates, showing Butt Joints in Boiler Barrel. Scale 1/8th.*

Fig. 19. *Enlarged Section of Thick-edge Plates, showing Flange Joint at end of Boiler Barrel. Scale 1/8th.*



FLANGING MACHINE.

Fig. 20. *Transverse Section.*

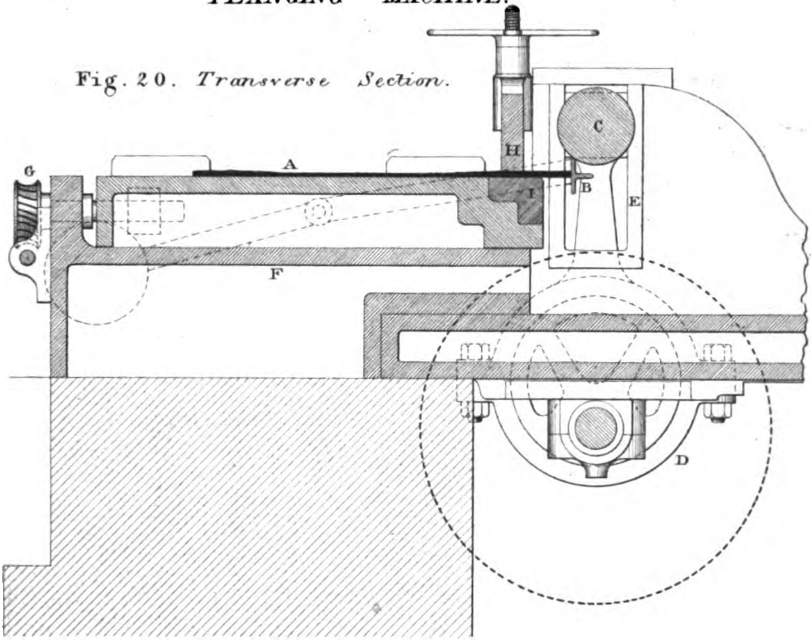
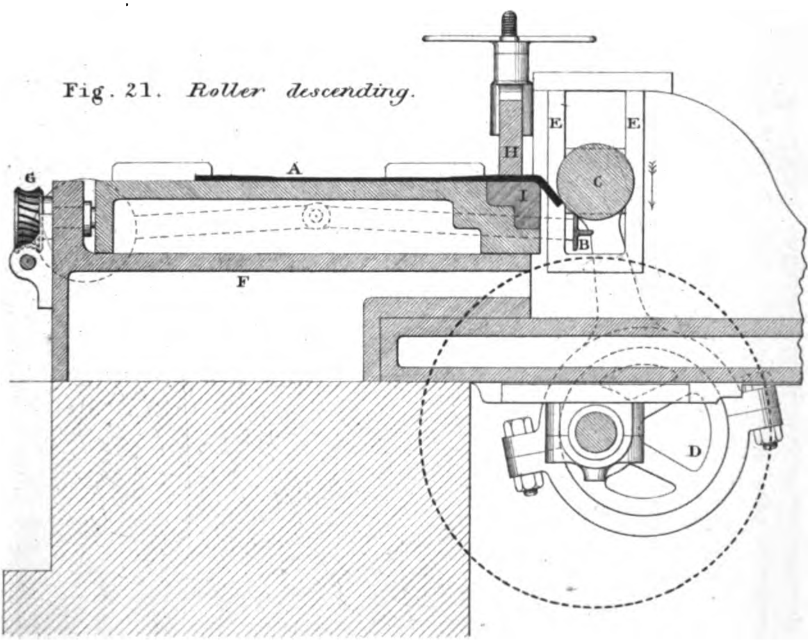


Fig. 21. *Roller descending.*



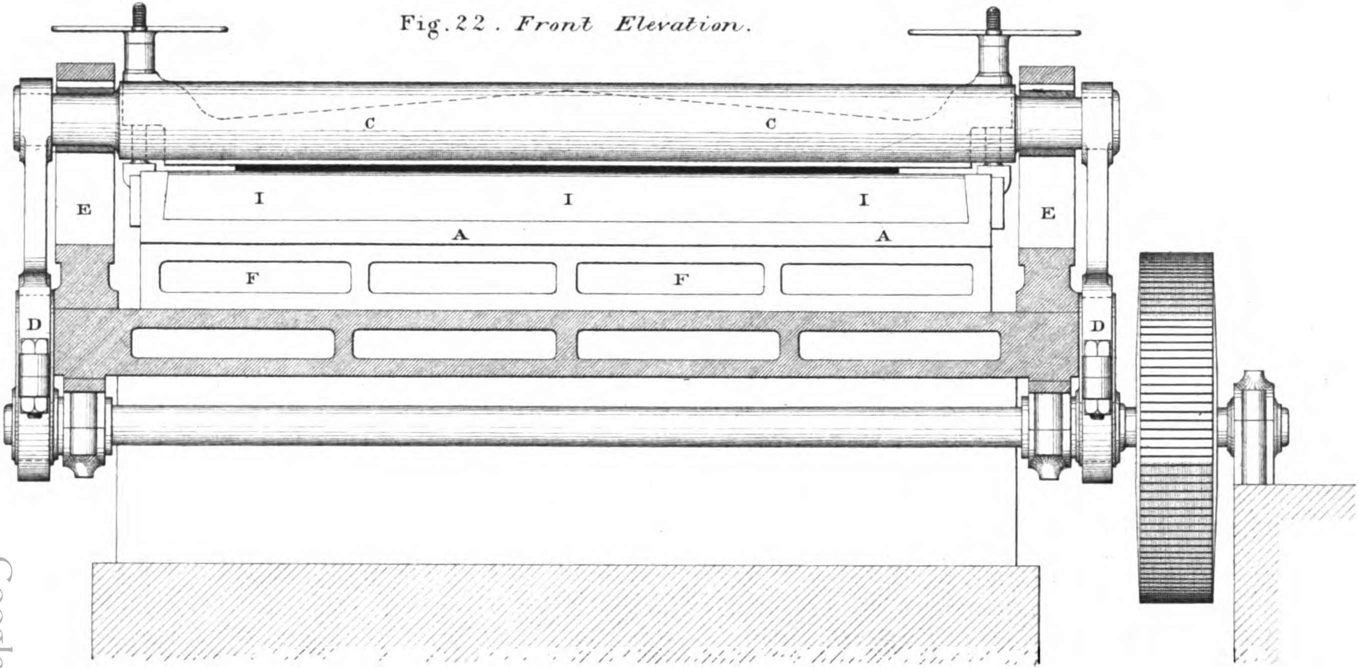
Scale 1/24th. 0 1 2 3 4 5 *Feet.*

(Proceedings Inst. M.E. 1866. Page 56.)

CORROSION OF LOCOMOTIVE BOILERS.

FLANGING MACHINE.

Fig. 22. *Front Elevation.*

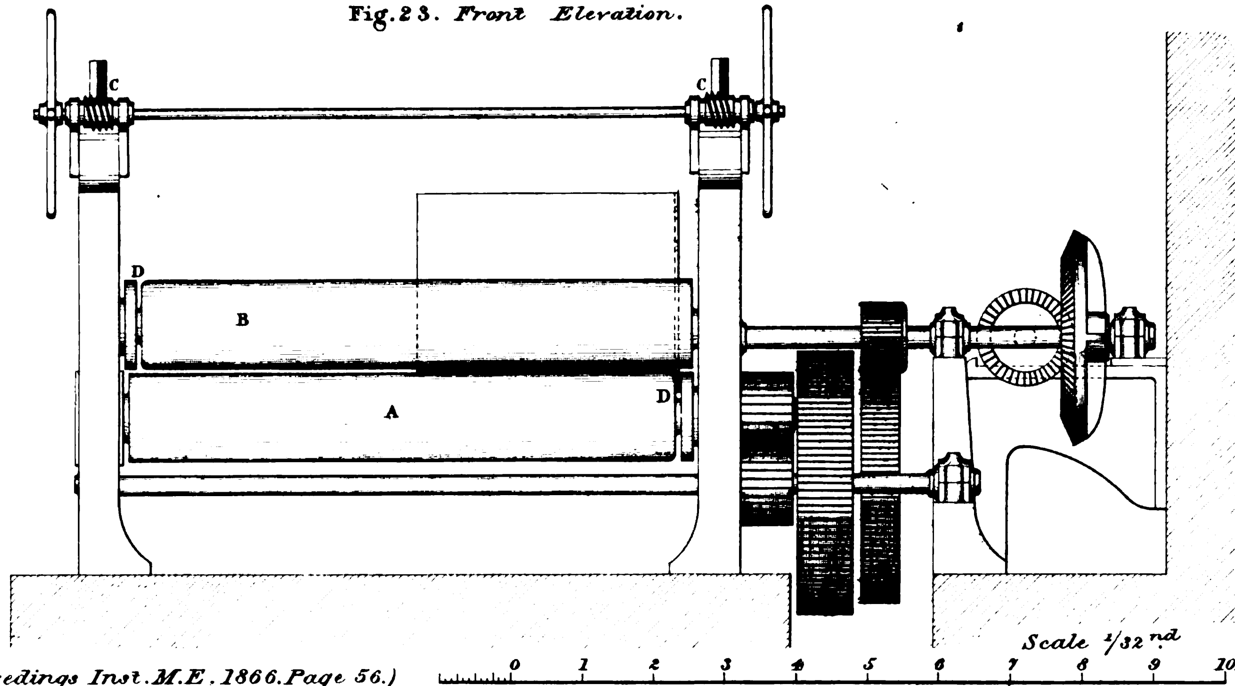


Scale 1/24th. 0 1 2 3 4 5 Feet.

CORROSION OF LOCOMOTIVE BOILERS. *Plate 20.*

BENDING MACHINE.

Fig. 23. *Front Elevation.*



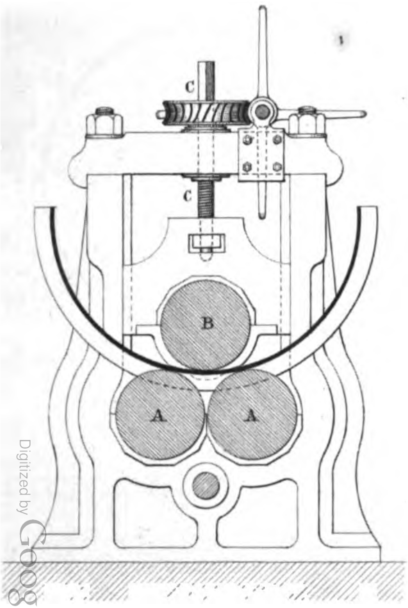
(Proceedings Inst. M.E. 1866. Page 56.)

CORROSION OF LOCOMOTIVE BOILERS.

Plate 21.

BENDING MACHINE.

Fig. 24. *Transverse Section.*



Scale 1/32nd.

0 1 2 3 4 5 Feet.

Fig. 25.

Section of Fluted Surface of Rolls.

Scale half full size.

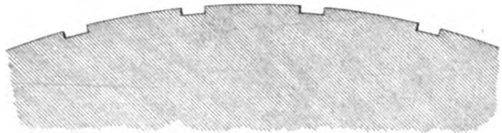


Fig. 27. *End Elevation.*

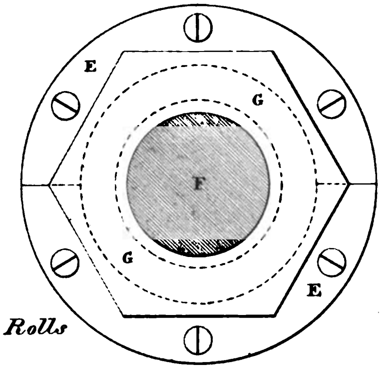
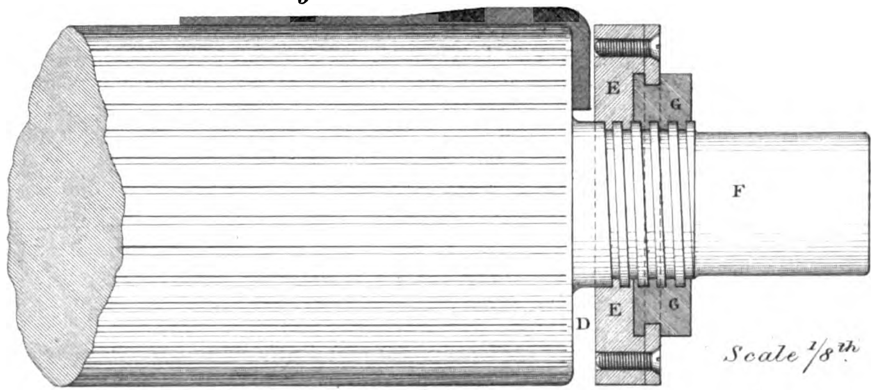


Fig. 26. *Section of Groove at end of Rolls to receive Flange of Plate.*



Scale 1/8th.

(Proceedings Inst. M.E. 1866. Page 56.)

CORROSION OF LOCOMOTIVE BOILERS.

WELDING ANVIL.

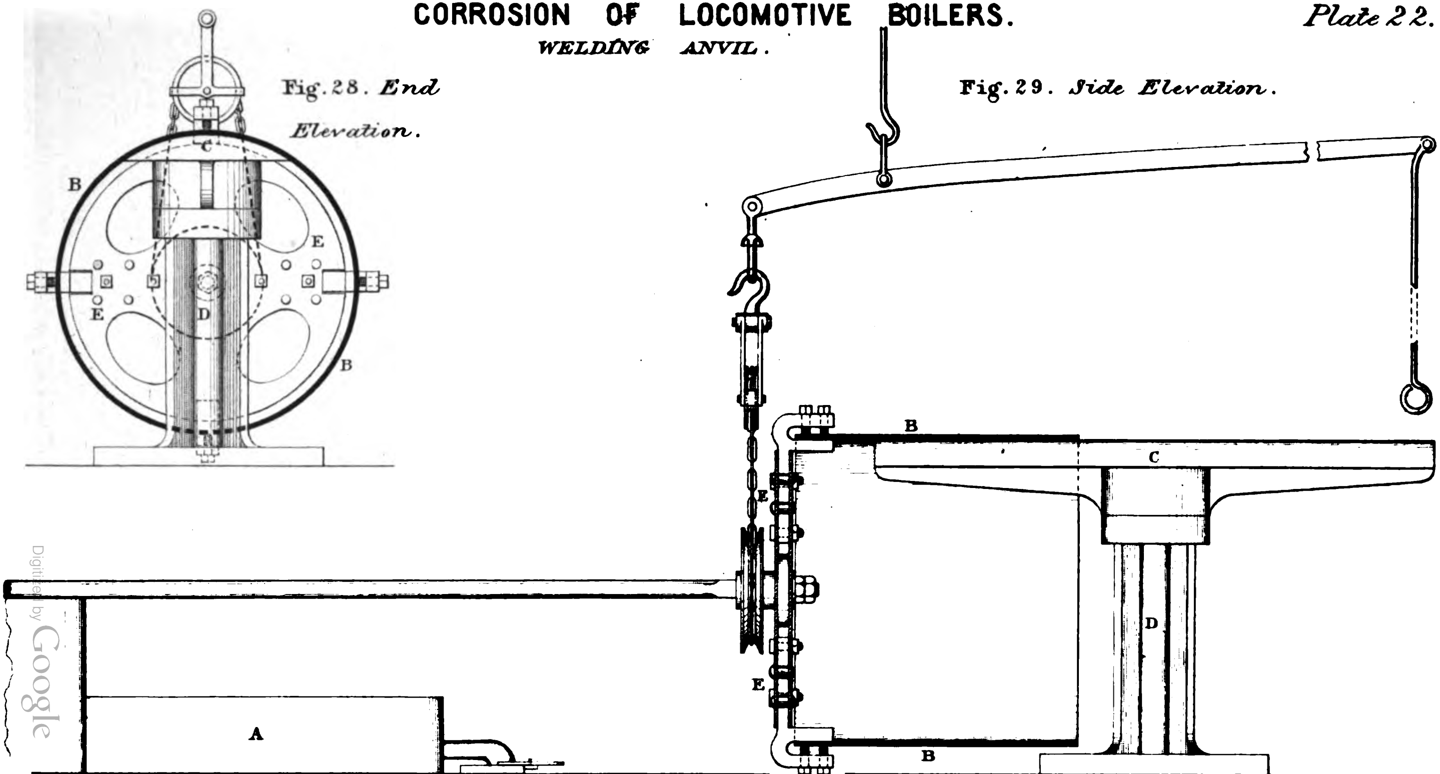


Fig. 28. *End Elevation.*

Fig. 29. *Side Elevation.*

 Scale $1/32^{nd}$. 0 1 2 3 4 5 6 7 8 9 10 Feet.

CORROSION OF LOCOMOTIVE BOILERS. *Plate 23.*

BLOCKING FURNACE.

Fig. 30. Vertical Section.

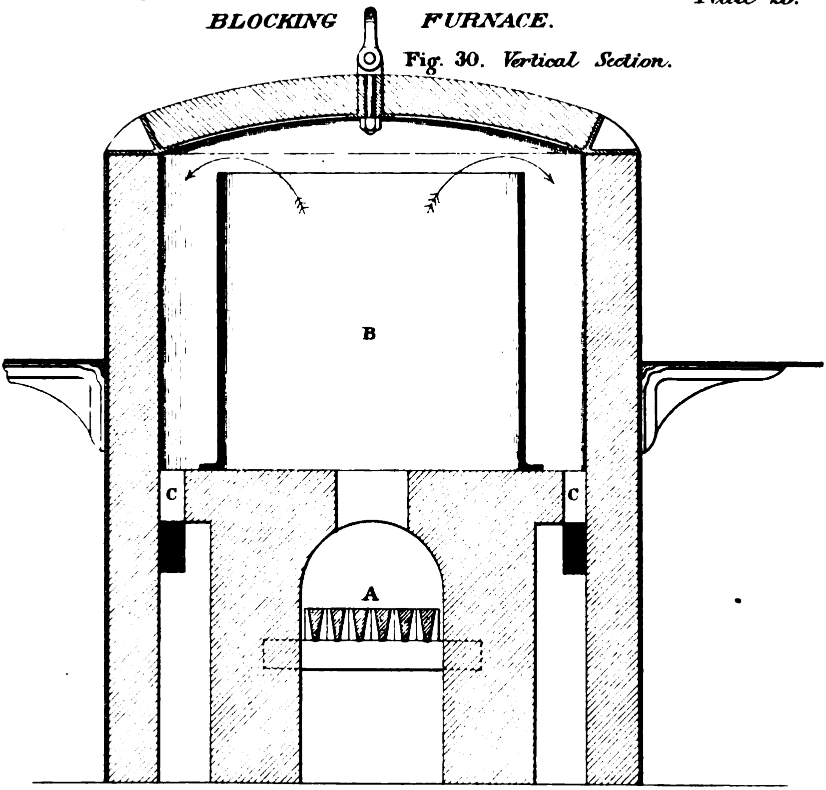
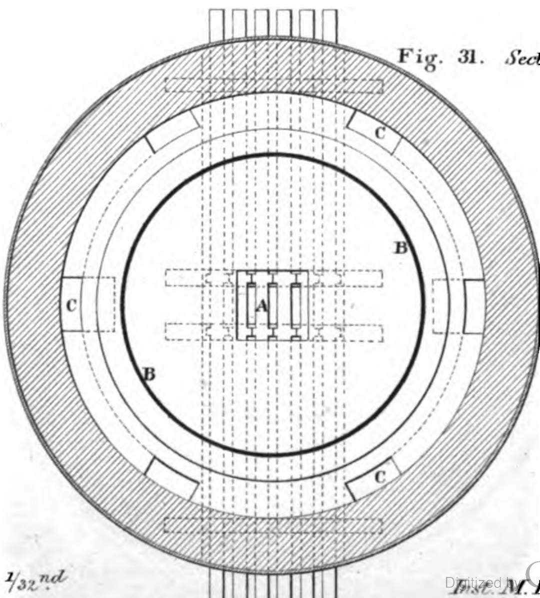


Fig. 31. Sectional Plan.



Scale 1/32nd

(Proceedings Inst. M. E. 1866. P.

BLOCKING PRESS.

Fig. 32. *Vertical Section.*

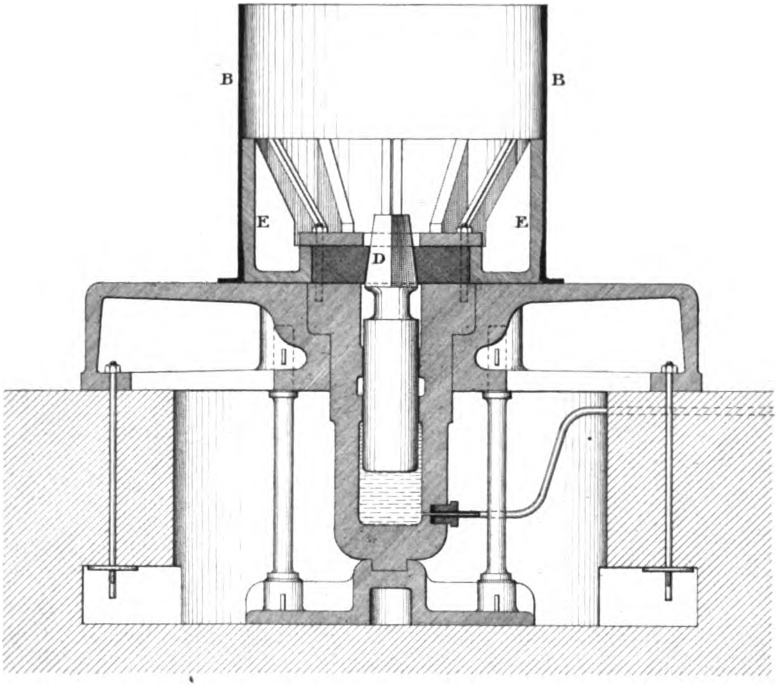
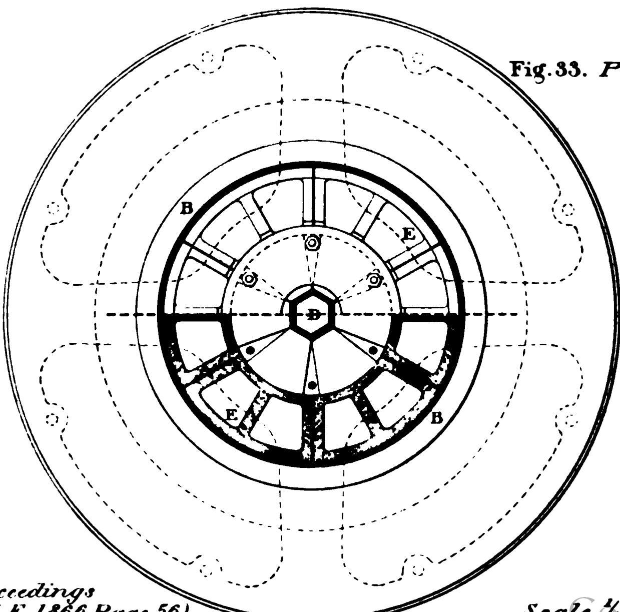


Fig. 33. *Plan.*



(Proceedings Inst. M.E. 1866. Page 56.)

Scale 1/32nd

0 1 2 3 4 5 6 7 8 9 10 Feet.

IMPROVED LOCK AND KEY. *Plate 25.*

Elevations of Fenby's Lock, with two front cover plates removed.

Fig. 1. *Bolt shot. Bit inserted preparatory to unlocking.*

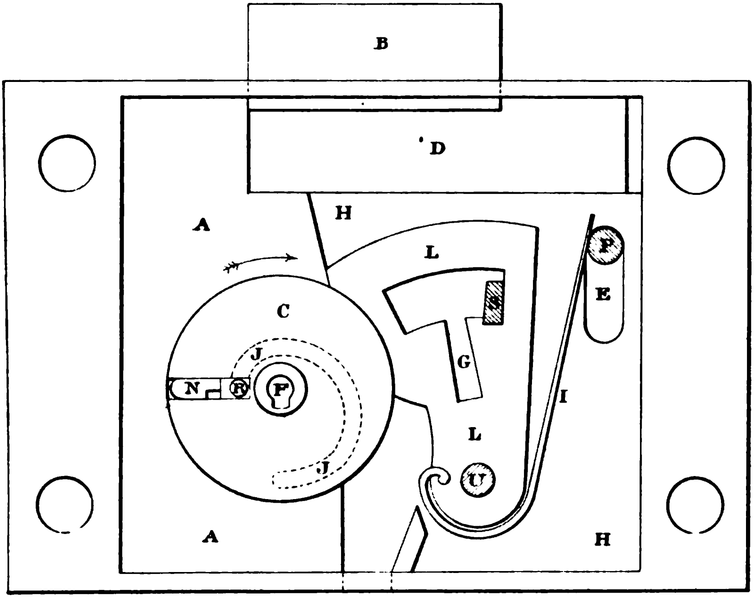
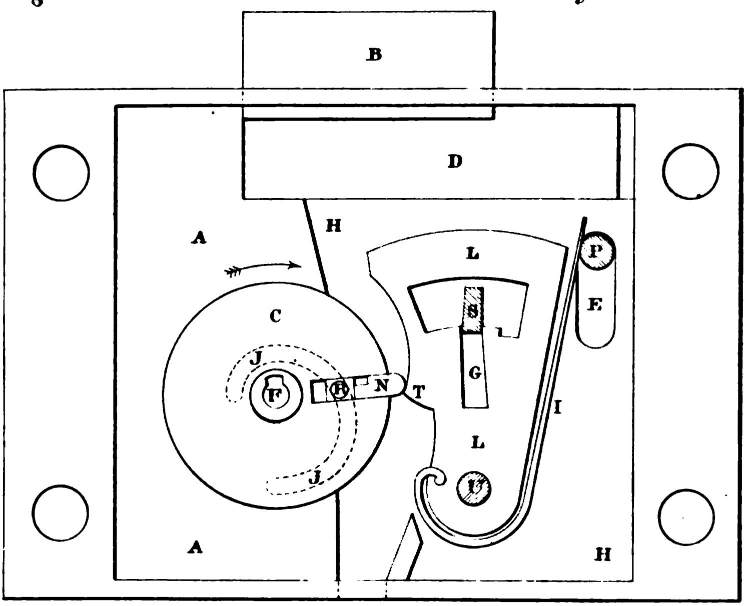


Fig. 2. *True Bit carried round, and raising Levers.*



(Proceedings Inst. M. E. 1866. Page 79.) *Scale 2/3 rds full size.*

Fig. 3. *True Bit falling inside the safe, after raising Levers ready for withdrawal of Bolt.*

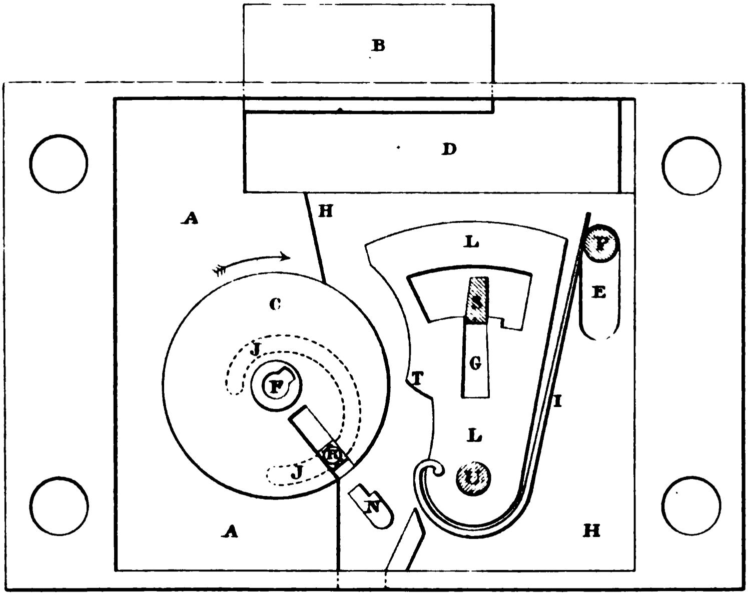
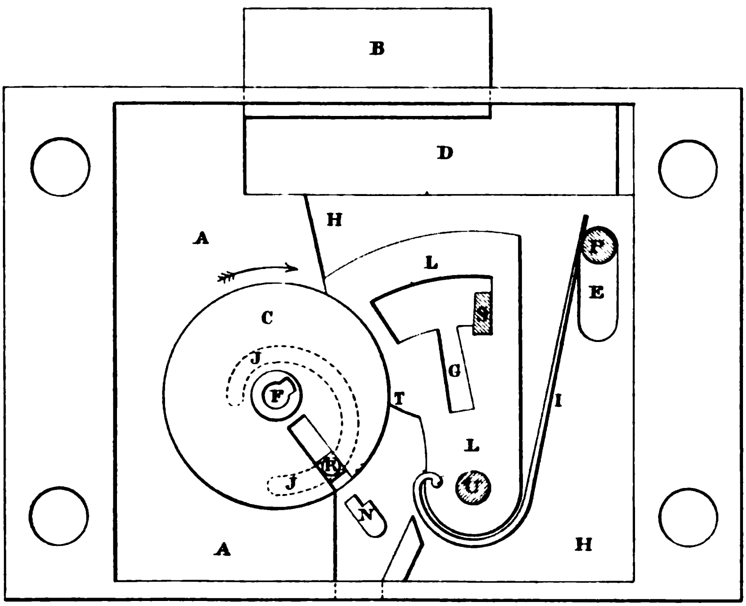


Fig. 4. *False Bit falling inside, after failing to raise Levers correctly.*



(Proceedings Inst. M. E. 1866. Page 79.) *Scale 2/3rds full size.*

Fig. 5 *Bolt withdrawn, after True Bit has fallen inside.*

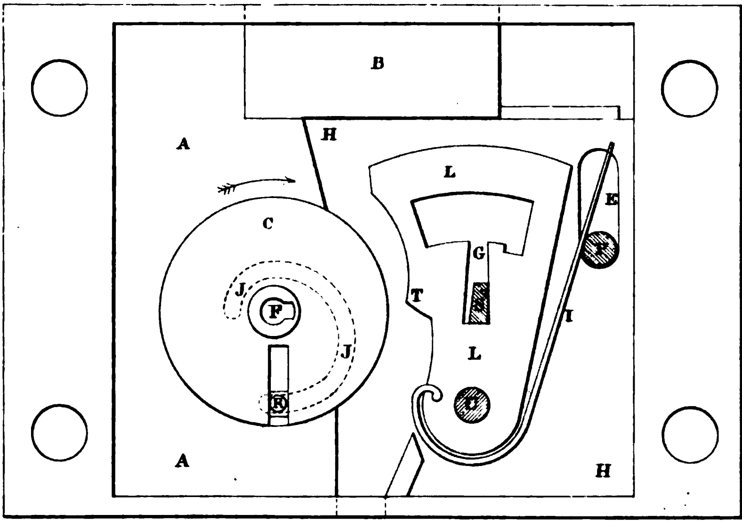


Fig. 6. *Main Bolt and Stump Bolt.*

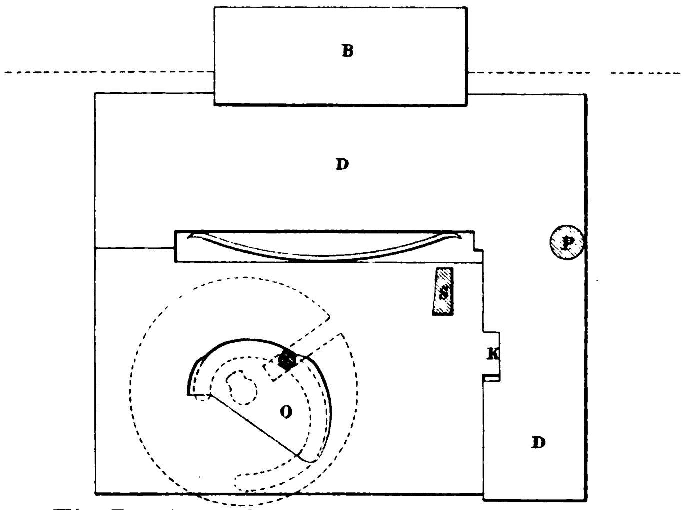
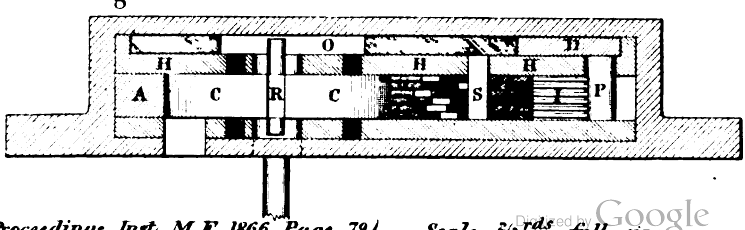


Fig. 7. *Sectional Plan of Lock.*



 Scale 2/3rds full size.

Plate 28

IMPROVED LOCK AND KEY.

Fig. 8. Stem of Key.

Full size.

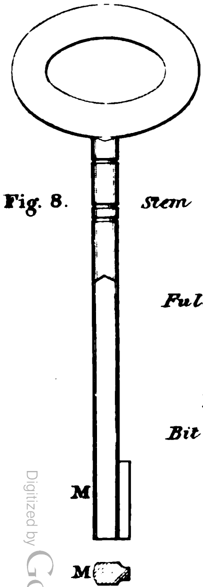


Fig. 9. Bit of Key.

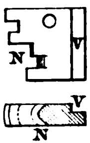


Fig. 10. Transverse Section of Key Cutting Machine.

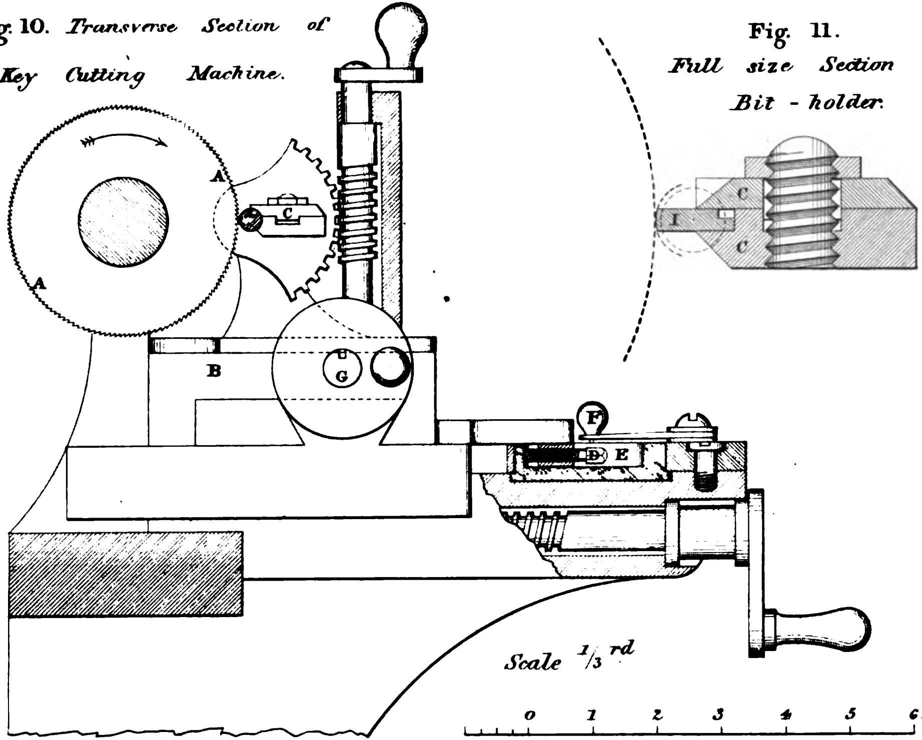


Fig. 11. Full size Section of Bit - holder.

IMPROVED LOCK AND KEY.

Plate 29.

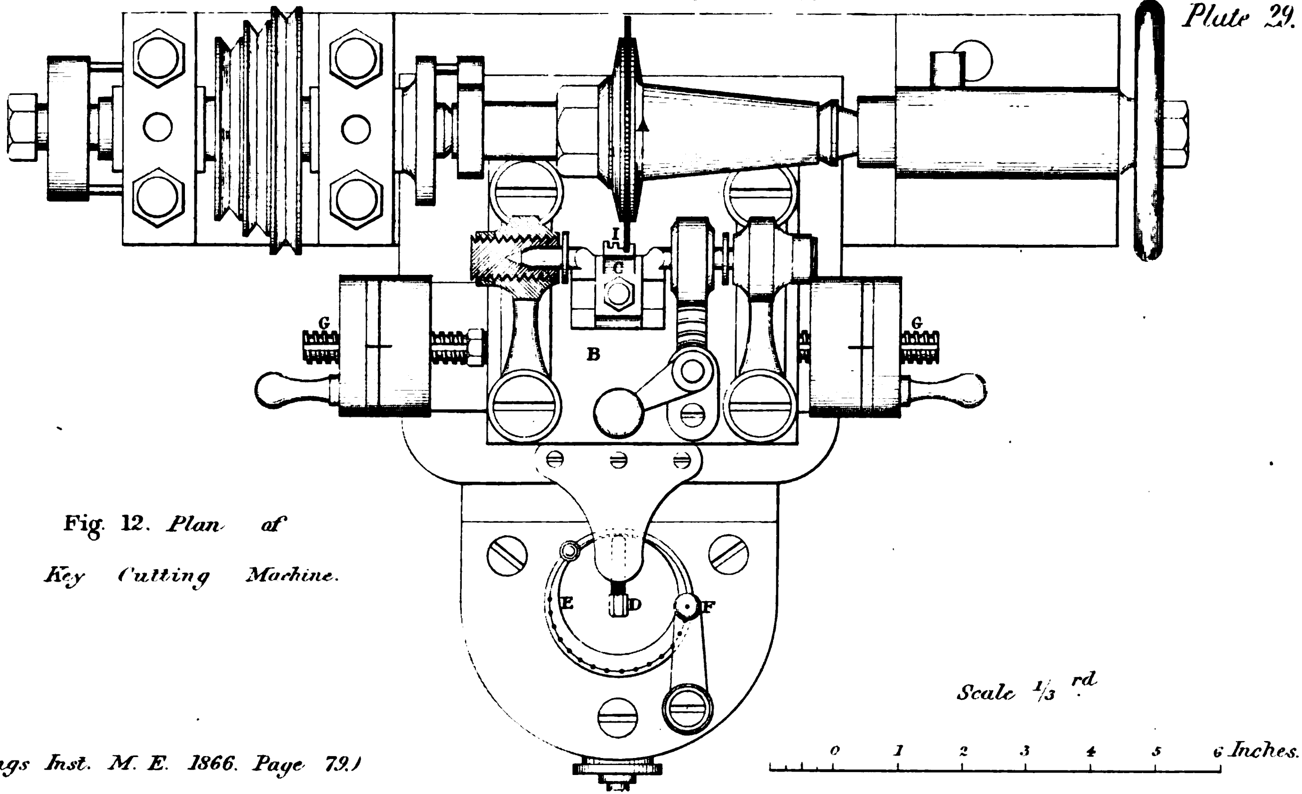


Fig. 12. *Plan of*

Key Cutting Machine.

(Proceedings Inst. M. E. 1866. Page 79.)

Fig. 13. *Egyptian Lock.* *Scale 1/3 rd*

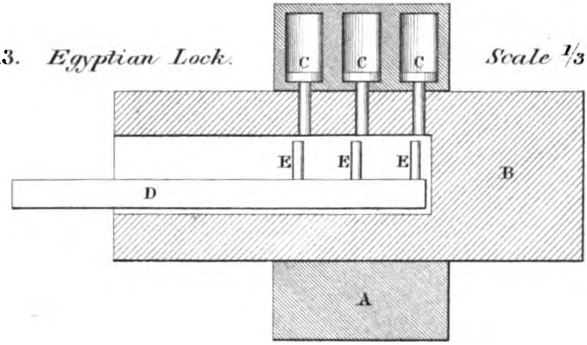


Fig. 14. *Lever Lock.* *Scale 2/3 rds*

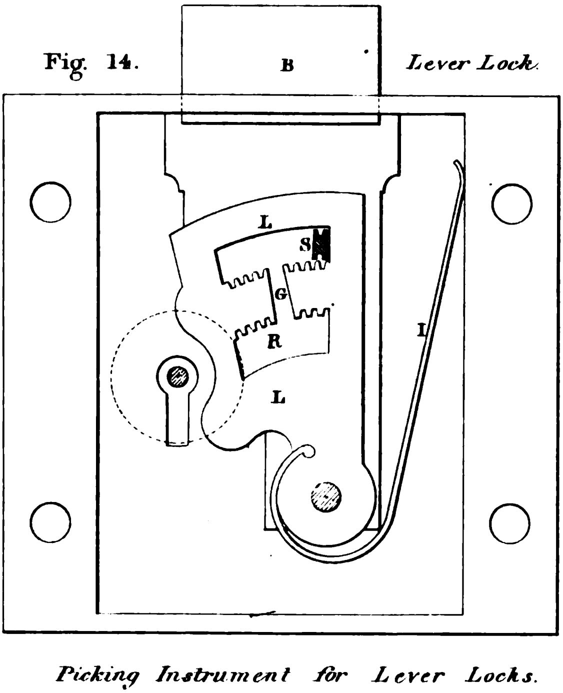
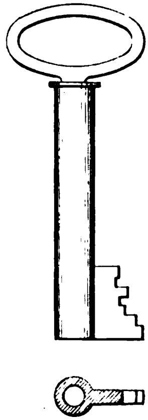


Fig. 15. *Key of Lever Lock.*



Picking Instrument for Lever Locks. *Scale 1/3 rd*

Fig. 16.

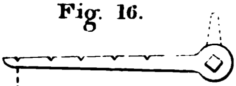


Fig. 17.

Fig. 18.

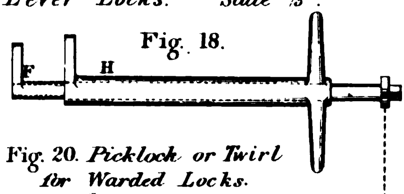
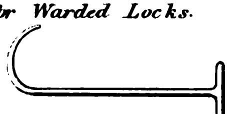


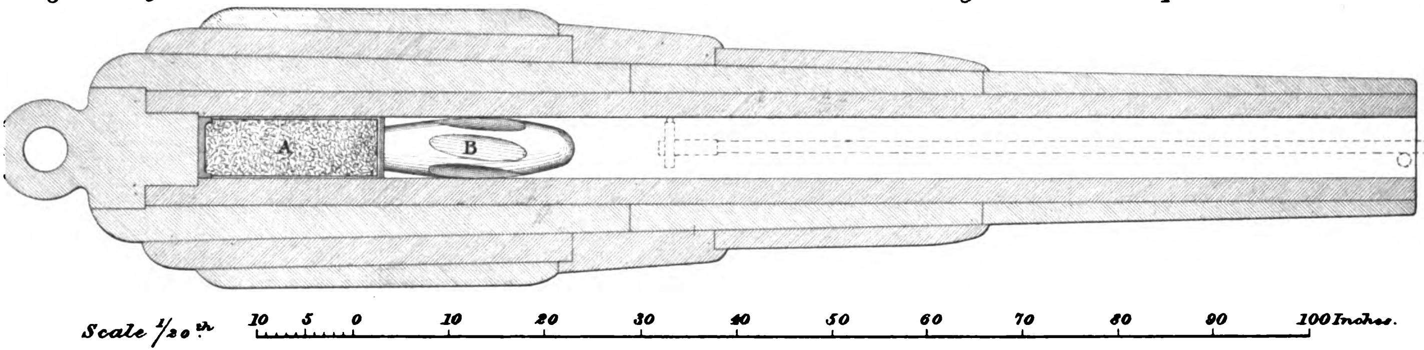
Fig. 19. *Key of Warded Lock.*

Fig. 20. *Picklock or Twirl for Warded Locks.*



PROOF OF GUNS BY MEASUREMENT. Plate 31.

Fig. 1. *Longitudinal Section of 7 inch Whitworth Gun, with Measuring Instrument placed in the bore.*



Scale 1/20th.

Fig. 2. *Plan of Shot.*

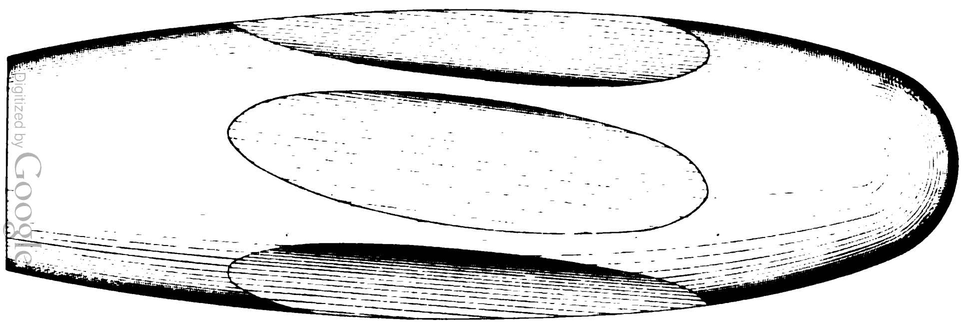
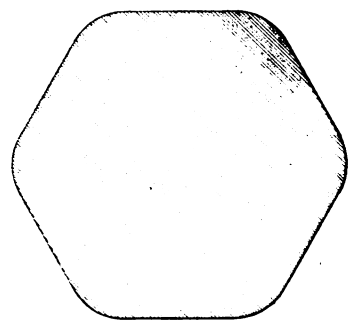


Fig. 3. *Transverse Section of Shot.*



Scale 1/2th.

(Proceedings Inst. M.E. 1866. Page 105.)

PROOF OF GUNS BY MEASUREMENT.

Plate 32.

Fig. 4. *Detail of Measuring Instrument.*

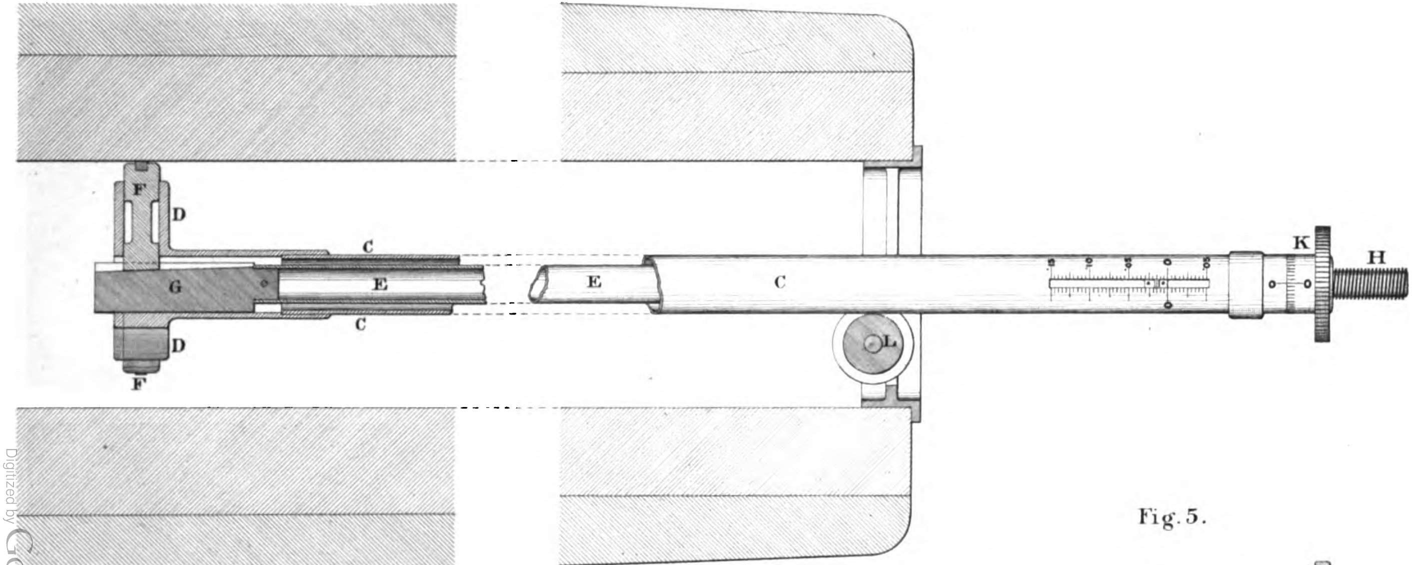
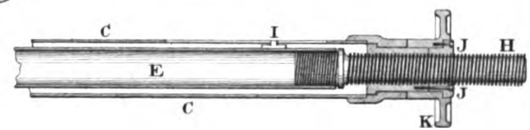


Fig. 5.



Scale 1/5th. 0 5 10 15 Inches.

(*Proceedings Inst. M.E. 1866. Page 105.*)

PROOF OF GUNS BY MEASUREMENT. Plate 33.

Fig. 6. Transverse Section of Measuring Instrument.

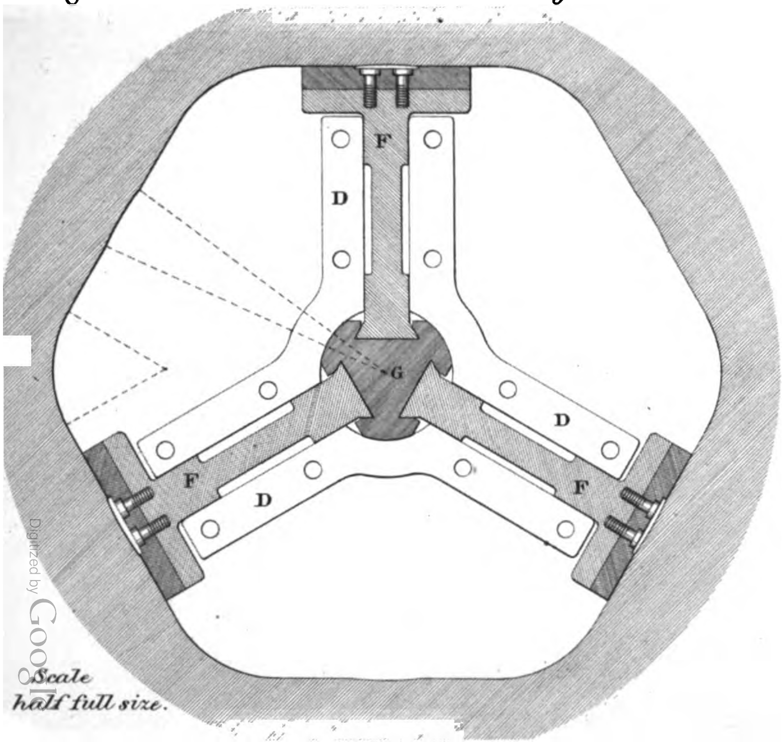


Fig. 7. Platinum Vent. Scale 1/15th.

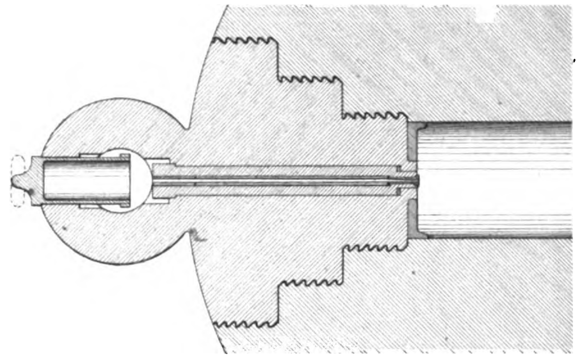
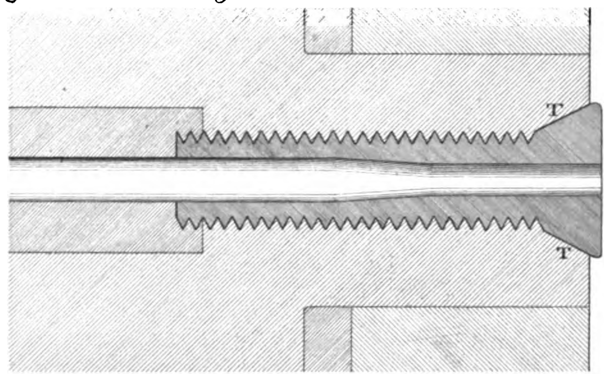
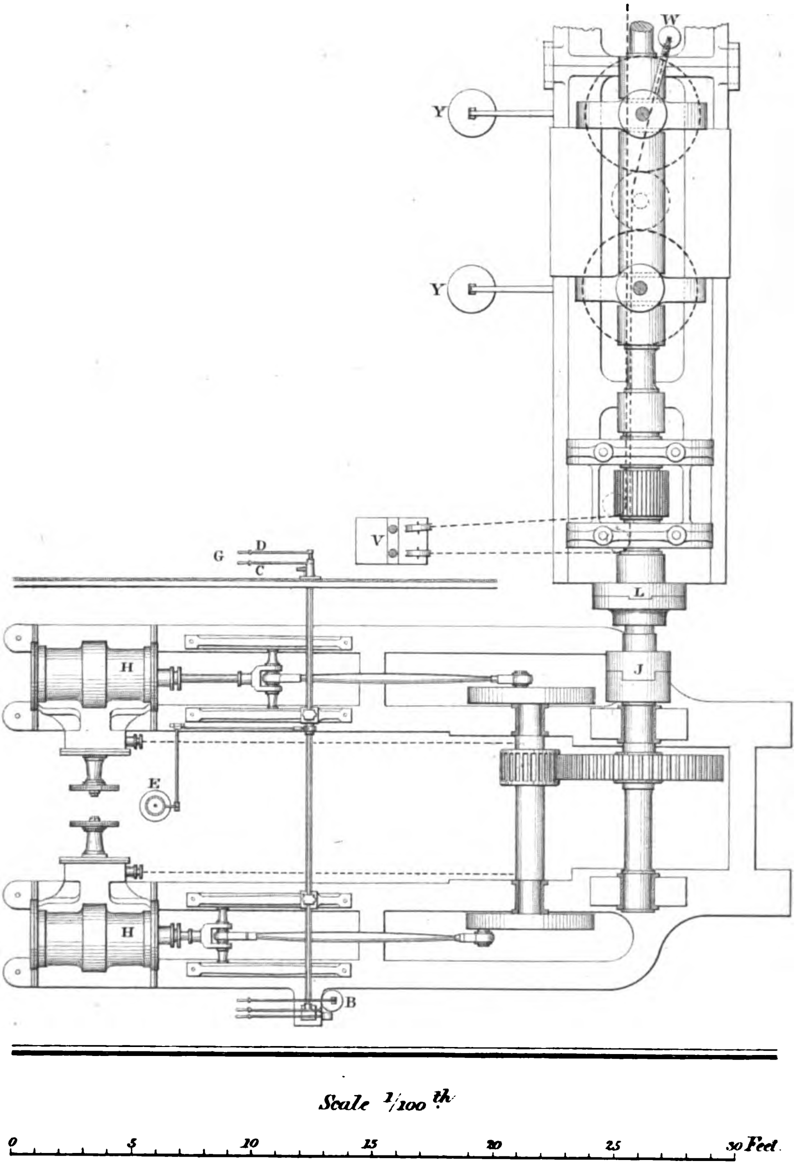


Fig. 8. Full size Longitudinal Section of Vent Piece.



(Proceedings Inst. M.E. 1866. Page 105.)

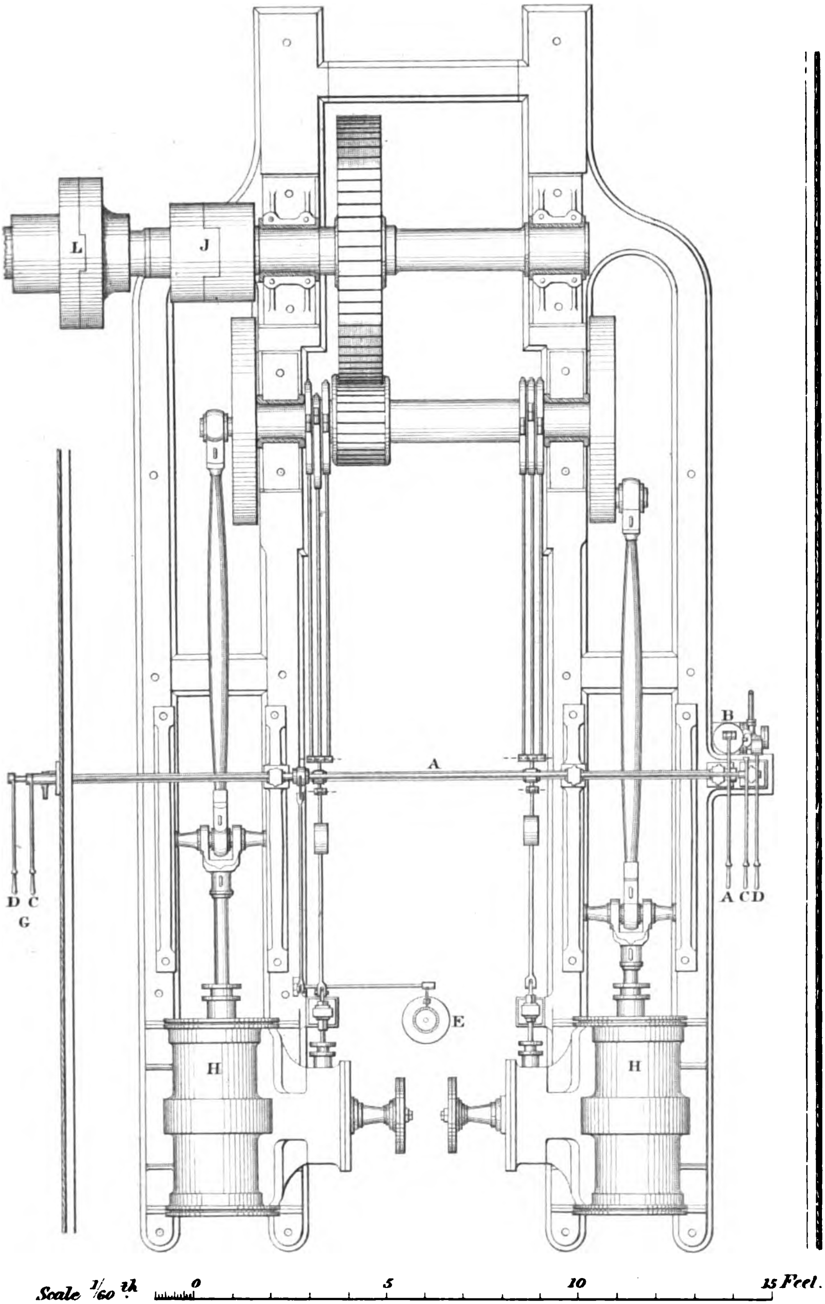
Fig. 1. *General Plan of Rolling Mill and Engines:*



Scale 1/100 th.

REVERSING ROLLING MILL. Plate 35.

Fig. 2. Enlarged Plan of Engines.



(Proceedings Inst. M. E. 1866. Page 115.)

REVERSING ROLLING MILL.

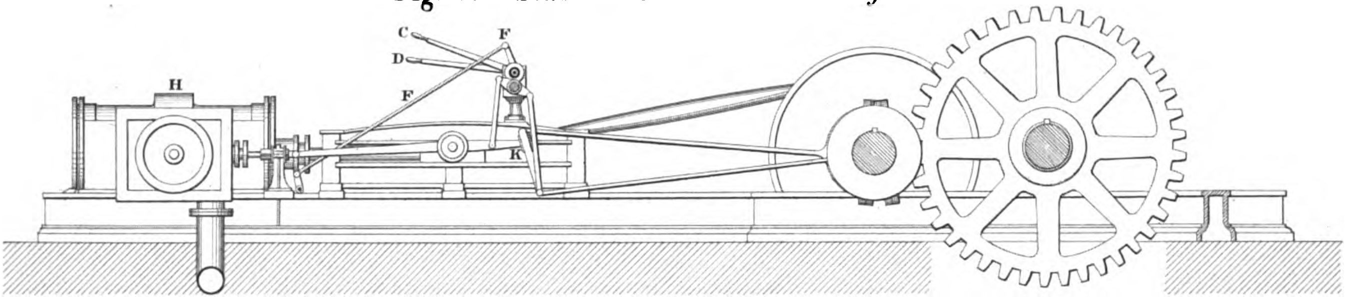


Fig. 3. Side Elevation of Engines.

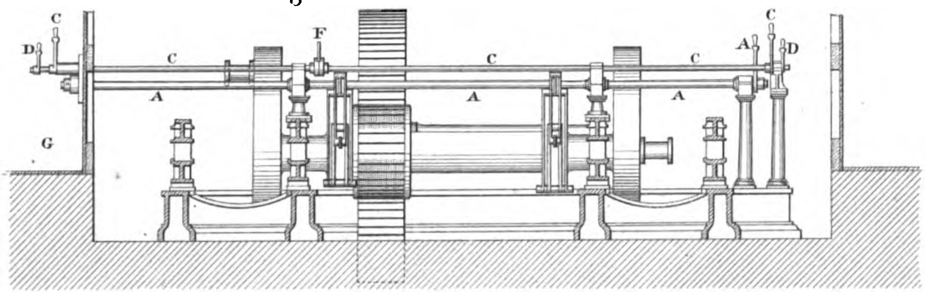


Fig. 4. Transverse Section.

REVERSING ROLLING MILL.

Plate 37.

Fig. 5. *Link Motion.*
Scale 1/20 th

Fig. 6. *Scale 1/10 th*

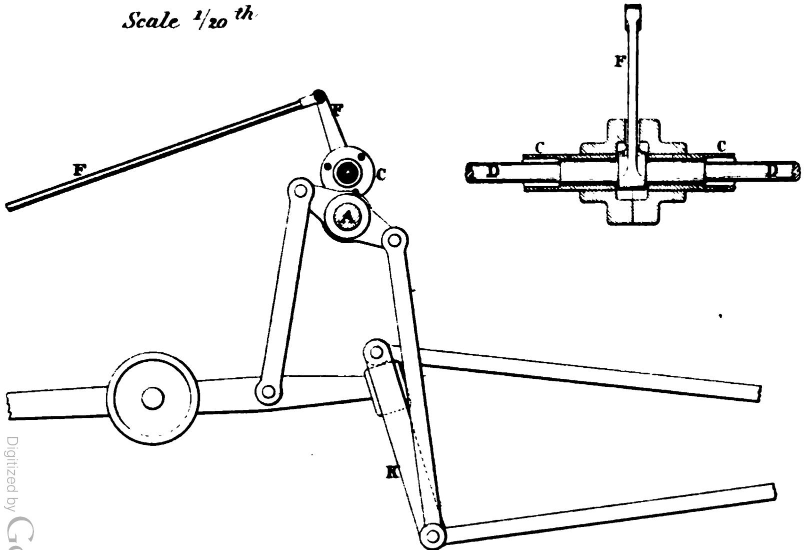
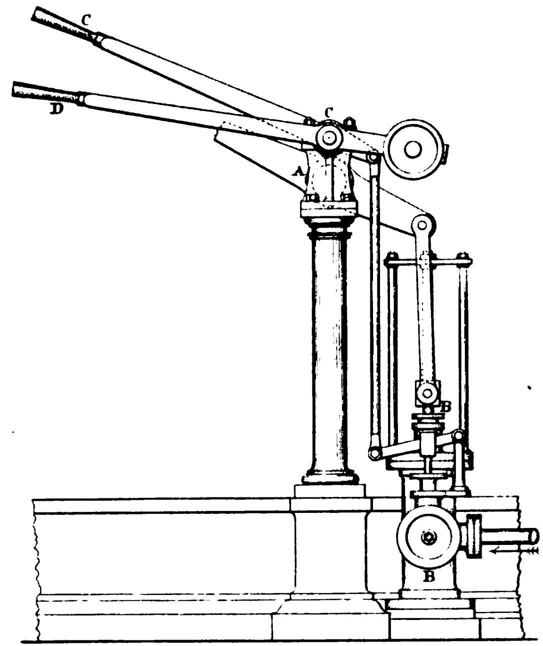


Fig. 7. *Hydraulic Reversing Gear.*
Scale 1/20 th

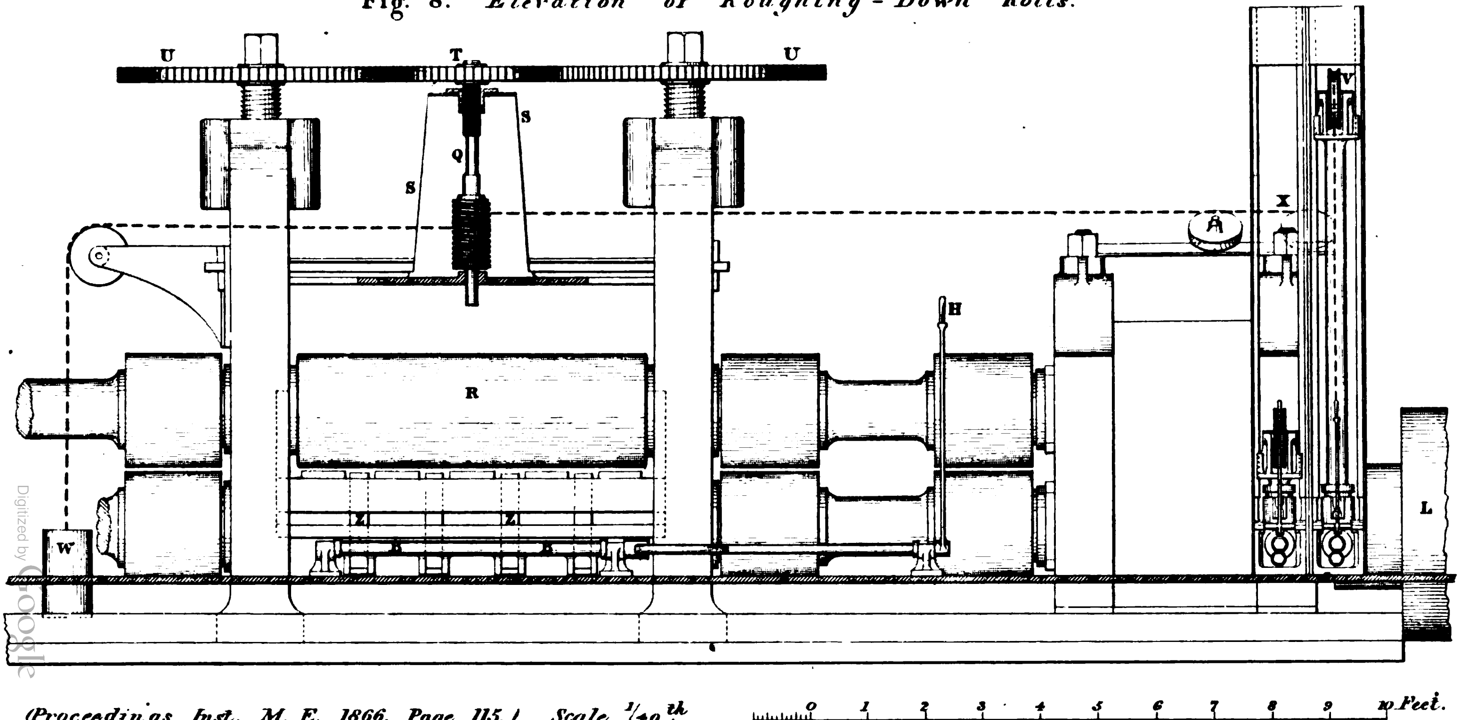


(Proceedings Inst. M. E. 1866. Page 115.)

REVERSING ROLLING MILL.

Plate 38.

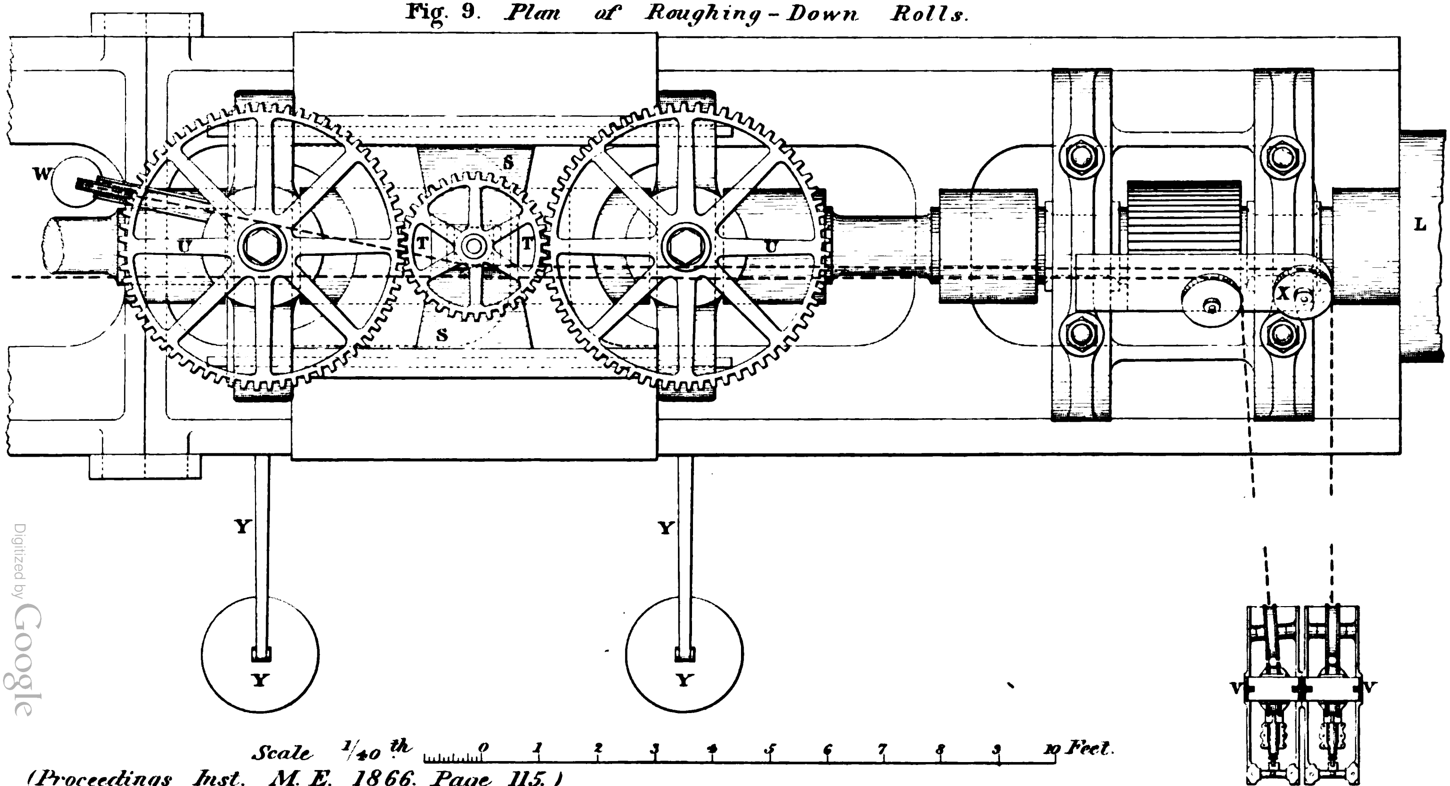
Fig. 8. *Elevation of Roughing - Down Rolls.*



(Proceedings Inst. M. E. 1866. Page 115.) Scale 1/40th.

REVERSING ROLLING MILL.

Fig. 9. *Plan of Roughing-Down Rolls.*

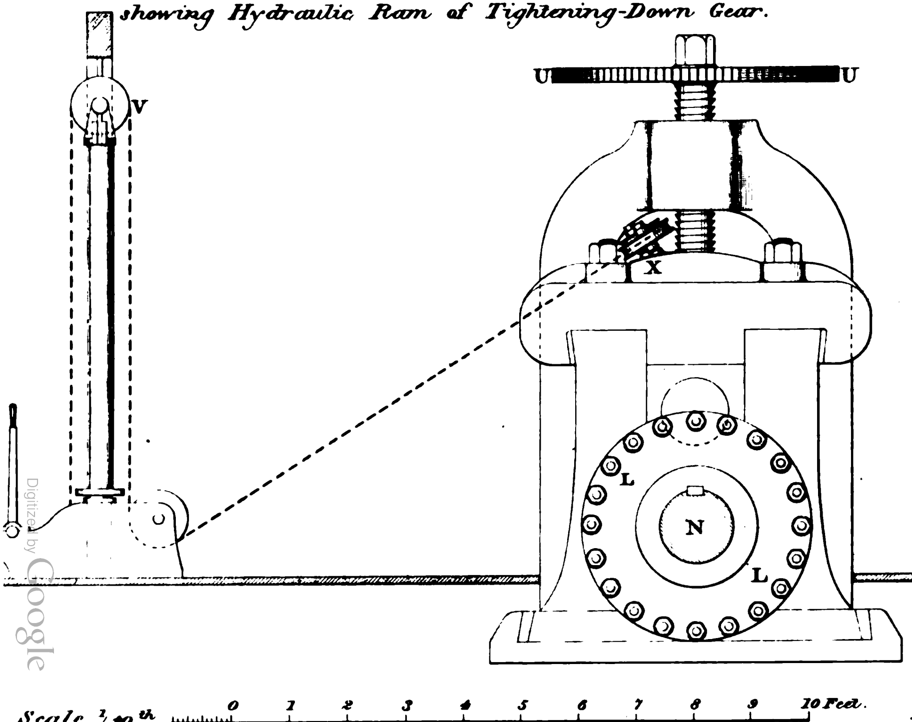


Scale 1/40 th

(Proceedings Inst. M. E. 1866. Page 115.)

REVERSING ROLLING MILL.

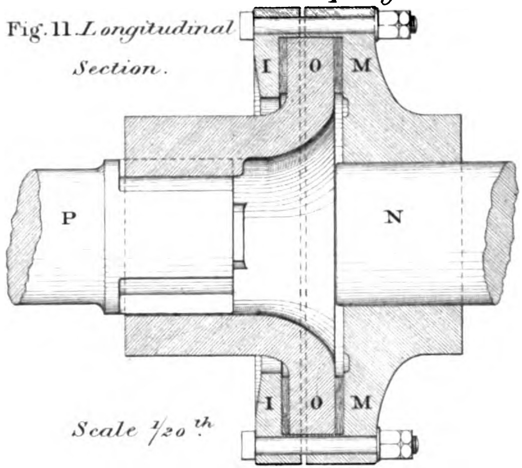
Fig. 10. *End Elevation of Rolling Mill, showing Hydraulic Ram of Tightening-Down Gear.*



Scale 1/40th.

Friction Coupling.

Fig. 11. *Longitudinal Section.*



Scale 1/20th.

Fig. 12. *Transverse Section.*

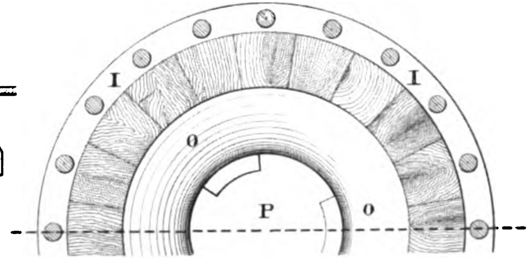


Plate 41.

REVERSING ROLLING MILL.

Fig. 13. Transverse Section through Housing.

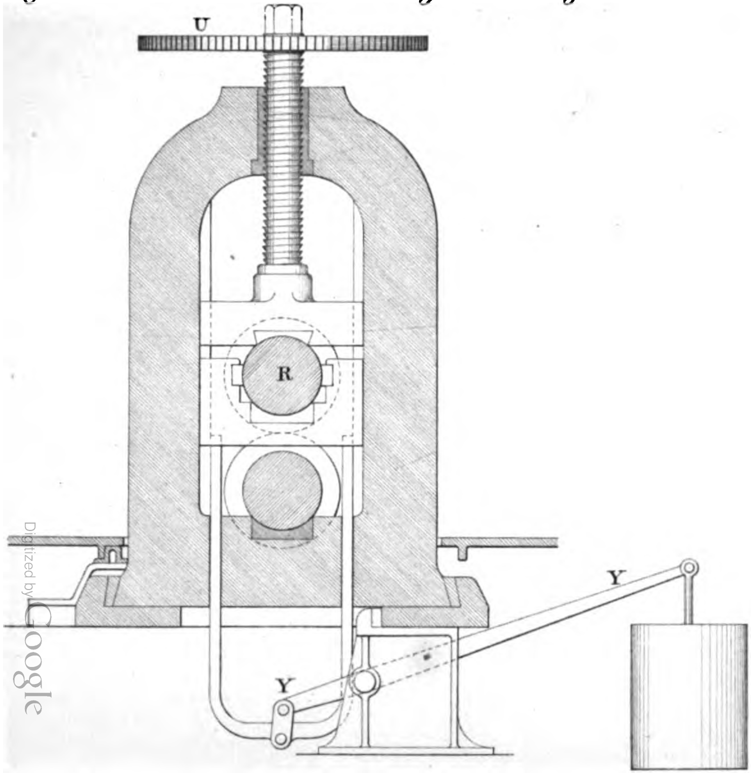
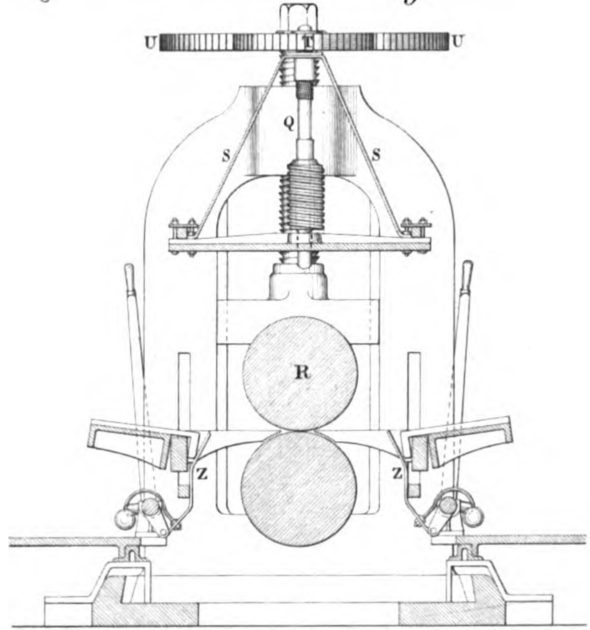


Fig. 14. Transverse Section through Rolls.

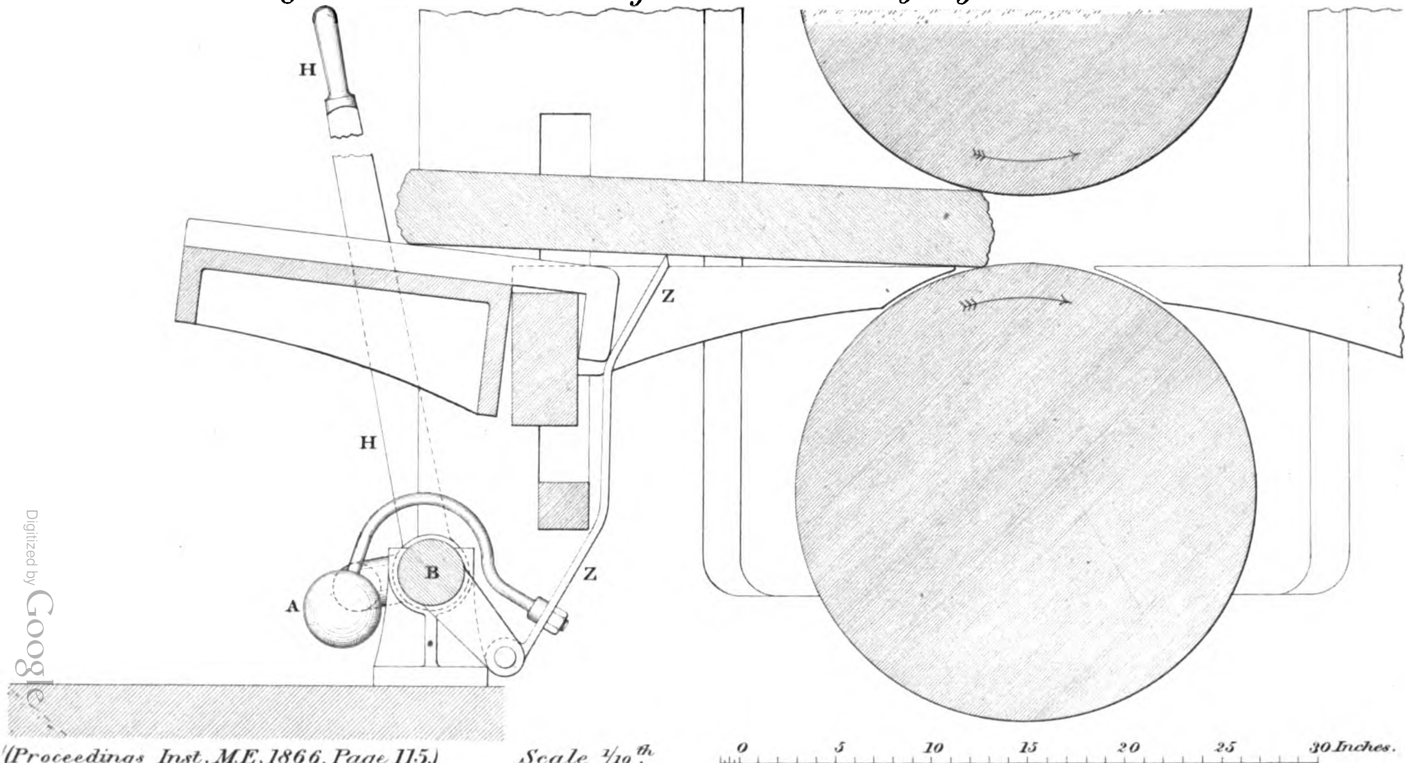


Scale 1/40th

(Proceedings Inst. M. E. 1866. Page 115.)

REVERSING ROLLING MILL.

Fig. 15. *Levers for entering Slabs into Roughing-Down Rolls.*



(Proceedings Inst. M.E. 1866. Page 115.) *Scale 1/10th.*

BOILER EXPLOSIONS.

Fig. 1. *Haystack Boiler exploded from want of stays. Diam. 14' 0" Wednesbury 1862.*

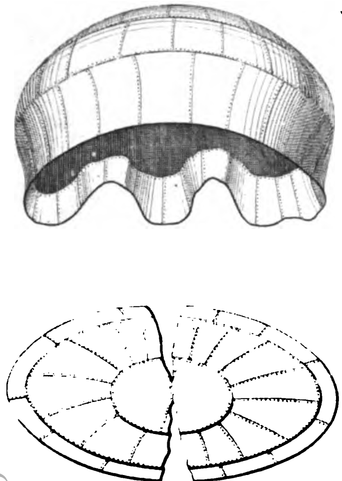


Fig. 2. *Scale 1/4th*

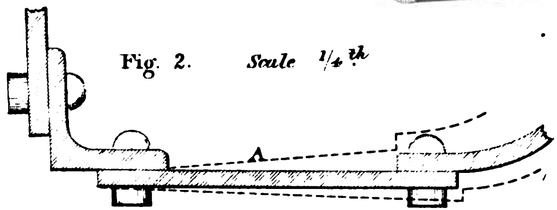


Fig. 3.

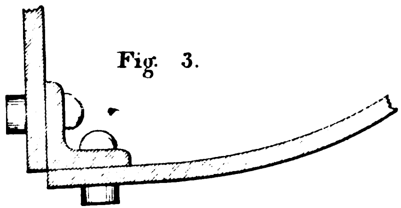


Fig. 4. *Lancashire Boiler collapsed by vacuum. Length 30' 0" Diam. 8' 5" Bury 1865.*

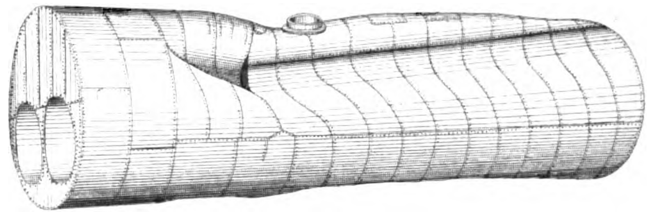
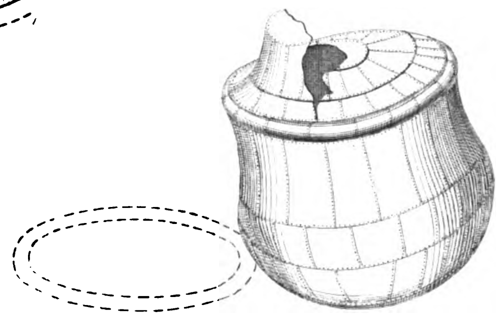


Fig. 5. *Haystack Boiler exploded from want of stays. Diam. 12' 0" Smethwick 1862.*



BOILER EXPLOSIONS.

Plate 44.

Fig. 6. *Plain Cylindrical Boiler*
exploded from injury over fireplace.
Length 34′0″ Diam. 5′6″
Darlaston 1863.

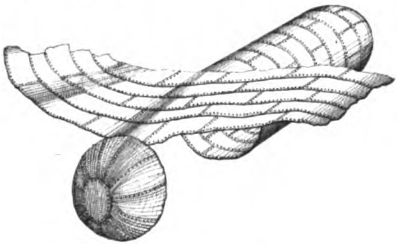
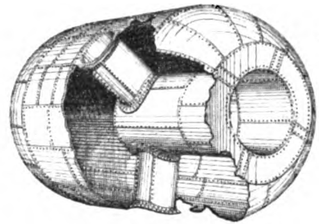
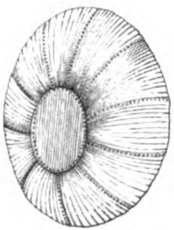


Fig. 7. *Three-Furnace Upright Boiler*
exploded from corrosion of bottom.
Height 17′4″ Diam. 9′0″ Westbromwich 1864.





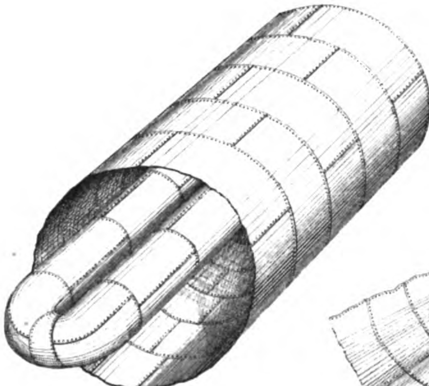
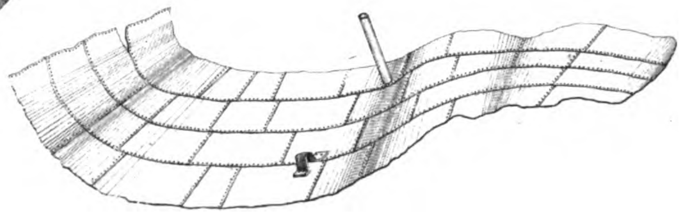


Fig. 8. *British Tube Boiler*
exploded from bad repair over fireplace.
Length 26′0″ Diam. 10′0″ Deepfields 1865.



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BOILER EXPLOSIONS.

Plate 45.

Fig. 9. Two-Furnace Upright Boiler exploded from weakness of angle iron at crown of centre tube.
Height 21'3" Diam. 9'0" Tube 4'8" diam.
Dudley 1862.

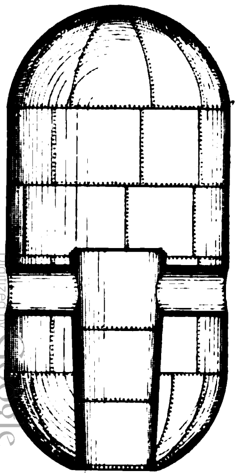
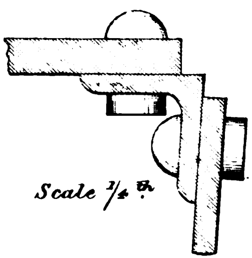


Fig. 10. Angle-iron Joint at crown of centre tube.



Scale 1/4 th.

Fig. 11. Cornish Boiler exploded from collapse of tube through want of strengthening rings.
Length 35'0" Diam. 7'0" Tube 4'0" diam.
Burton 1865.

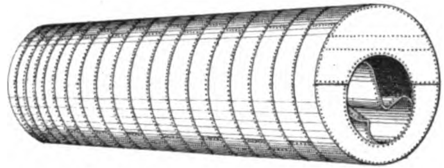


Fig. 12. Internally Fired Upright Boiler exploded from weakness of fireplace.
Height 20'0" Diam. 9'6"
Stoke-upon-Trent 1863.

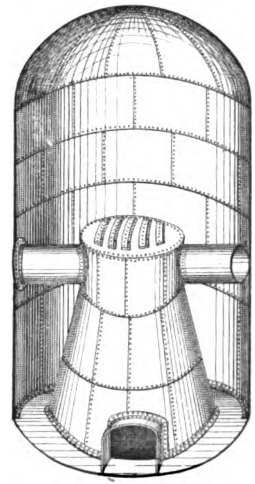
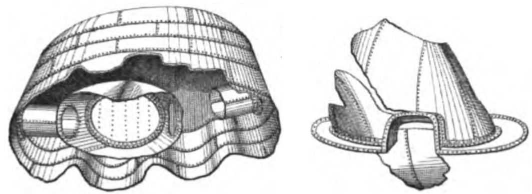


Fig. 13. Appearance after explosion.



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BOILER EXPLOSIONS.

Fig. 14. Steam Dome of Weak shape.

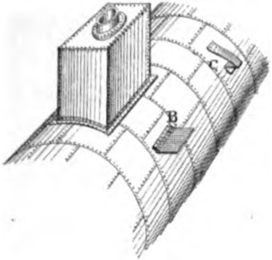


Fig. 15. Cornish Boiler exploded from corrosion of bottom.
Length 30′0″ Diam. 6′0″ Tube 4′0″ diam. at fire, 2′6″ beyond.
Loughborough 1863.

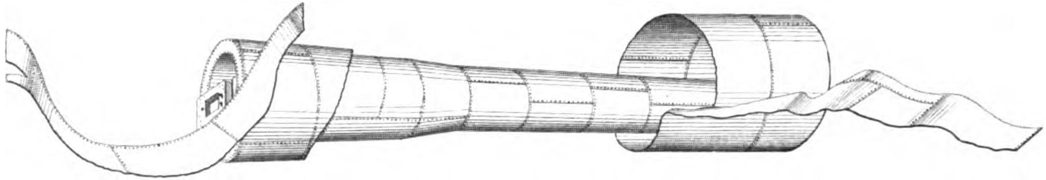
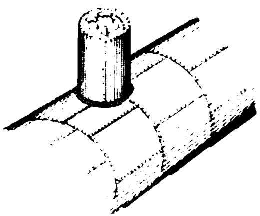


Fig. 16. Explosion from too large manhole in steam dome 2′6″ diam.
Birmingham 1865.



Explosions from too large manhole.

Fig. 17. Diam. 2′6″
Manhole 1′6″ × 1′1″
Walsall 1865

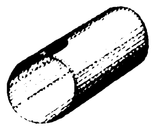


Fig. 18.
Diam. 2′6″
Leicester 1866.

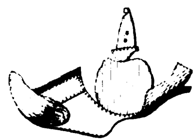
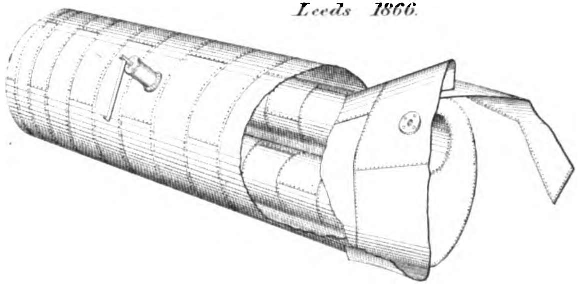


Fig. 19. Lancashire Boiler exploded from corrosion at bottom.
Length 25′0″ Diam. 7′0″ Tubes 2′5″ diam.
Leeds 1866.



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BOILER EXPLOSIONS.

Plate 47.

Fig. 20. Three-Furnace Upright Boiler exploded by overheating. Height 24'0" Diam. 7'9" Birmingham 1865

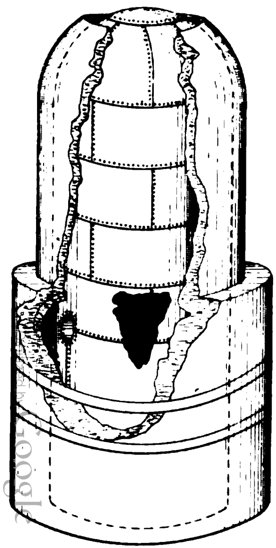


Fig. 21. Four-Furnace Horizontal Boiler. Tube collapsed from overheating Length 22'0" Diam 6'6" Kidderminster 1865.

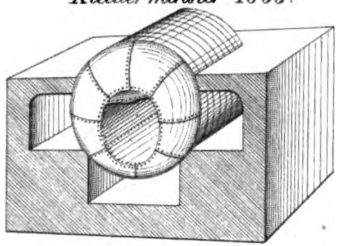


Fig. 22. Plain Cylindrical Boiler exploded from corrosion all along bottom where resting on brickwork. Length 25'0" Diam. 5'0" Wigan 1865.

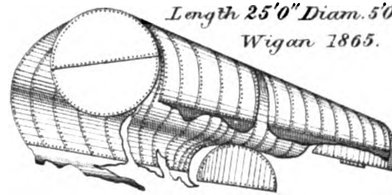


Fig. 23. Lancashire Boiler exploded from corrosion of bottom. Length 18'0" Diam. 8'0" Leeds 1865.

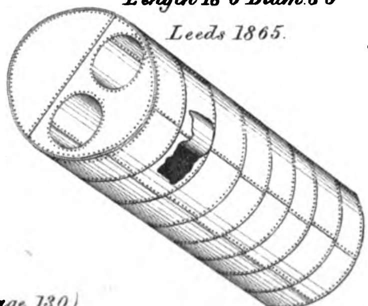


Fig. 24. Oval Boiler set upon middle wall, corroded into holes along bottom. Length 16'4" Height 6'6" Width 5'0"

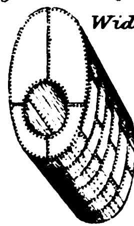


Fig. 25. Plain Cylindrical Boiler exploded from corrosion of side. Length 21'0" Diam. 4'0" Sheffield 1865.

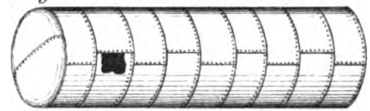
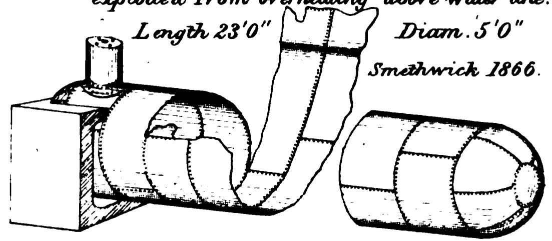


Fig. 26. Plain Cylindrical Boiler exploded from overheating above water line. Length 23'0" Diam. 5'0" Smethwick 1866.



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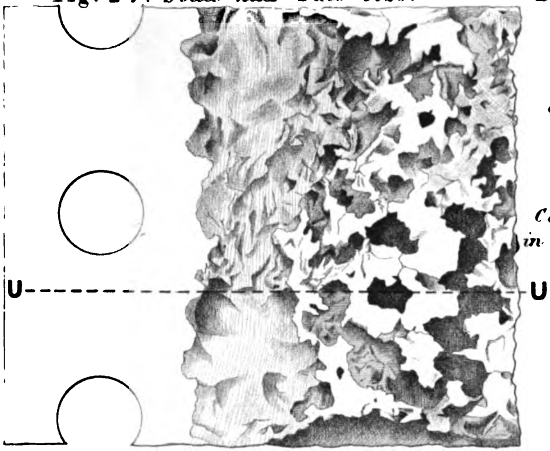
BOILER EXPLOSIONS.

Plate 48.

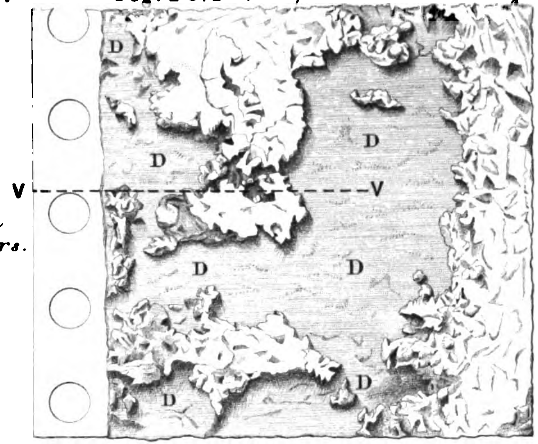
Internal Corrosion caused by bad feed water.

Fig. 27. Scale half full size.



Corrosion in 8 years.

Fig. 28. Scale 1/4th



Corrosion in 10 years.

Fig. 29. Full size section at U U (Fig. 27.)

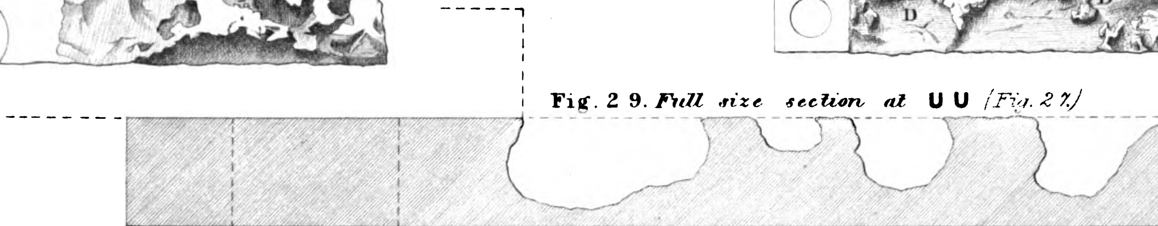
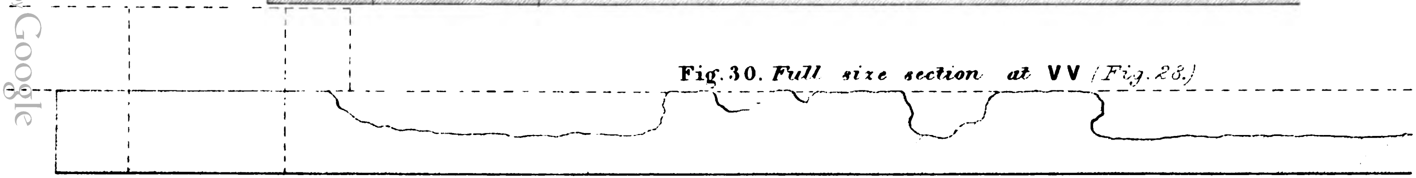


Fig. 30. Full size section at V V (Fig. 28.)



BOILER EXPLOSIONS.

Plate 49.

Fig. 31. *External Corrosion from covering with Ashes.*

Scale 1/4th.

Corrosion in 2 years.

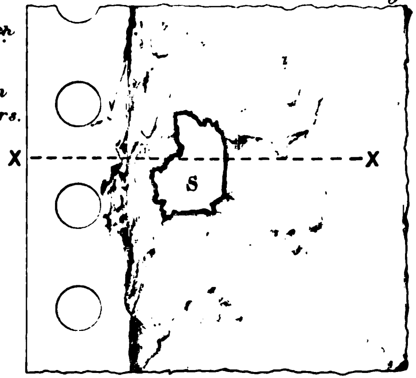
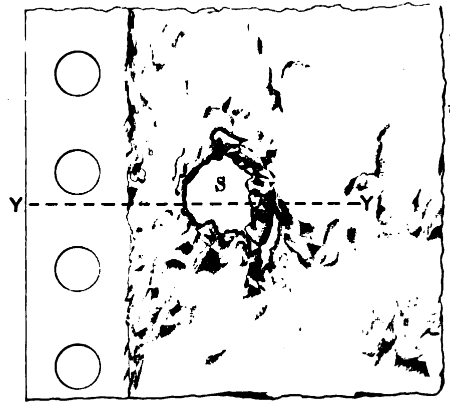


Fig. 32. *External Corrosion from covering with Sand.*

Scale 1/4th.

Corrosion in 8 years.



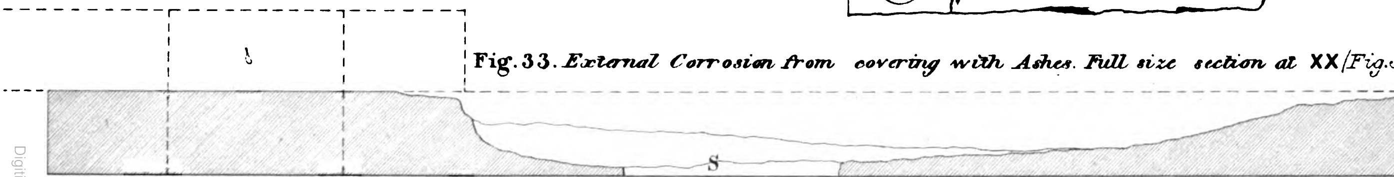


Fig. 33. *External Corrosion from covering with Ashes. Full size section at* XX *(Fig. 31.)*

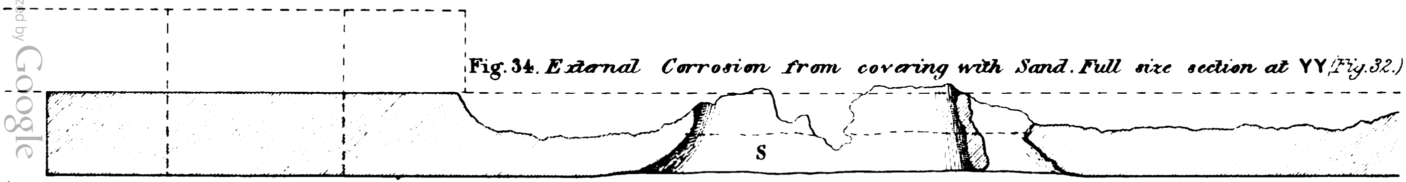


Fig. 34. *External Corrosion from covering with Sand. Full size section at* YY *(Fig. 32.)*

BOILER EXPLOSIONS.

Fig. 35. *Section of Faulty Rivetting and Caulking.*
Full size.

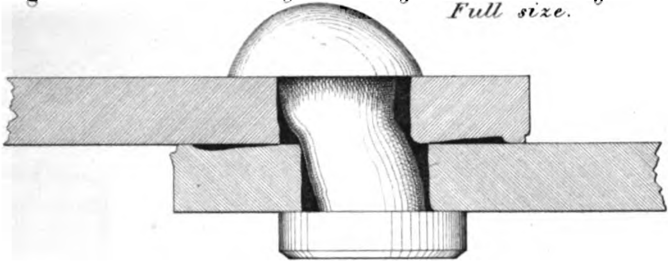


Fig. 36. *Lump of Scurf made up of chips from sides of boiler.*
Half full size.

Fig. 37. *Explosion of "Pocket" caused by thick scurf over fire.*
Plain Cylindrical Boiler externally fired. Diam. 4' 6"
Dudley. 1864. *Scale 1/8th.*

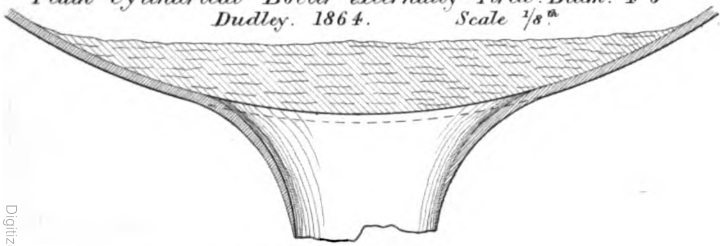


Fig. 38.
Channelling caused by Jet of steam and water from leaking rivet.
Scale 1/4th.

Corrosion in **4** *years.*

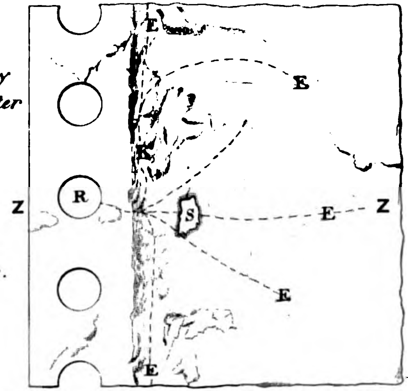
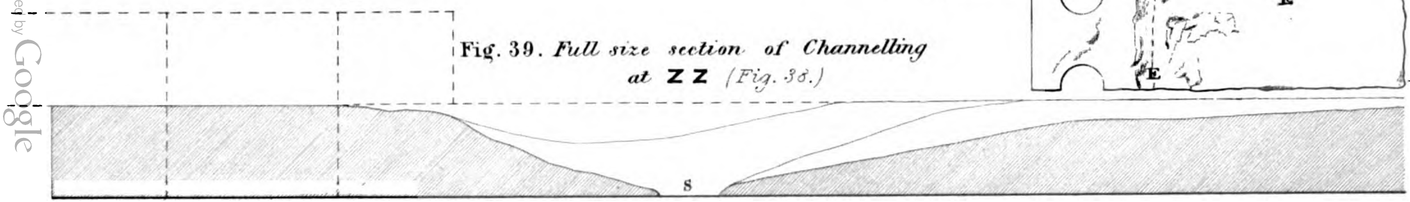


Fig. 39. *Full size section of Channelling at* **Z Z** *(Fig. 38.)*



BOILER EXPLOSIONS.

Plate 51.

Fig. 40.
Savery's Boiler.
Diam. 6' 0"

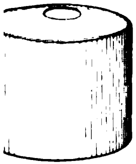


Fig. 41.
Tun Boiler.
Diam. 10' 0"

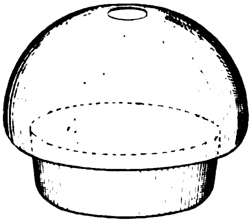


Fig. 42.
Flange Boiler.
Diam. 5' 0"

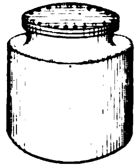


Fig. 43.
Smeaton's Boiler.
Cast-iron.
Height 10' 0" Diam. 6' 0"

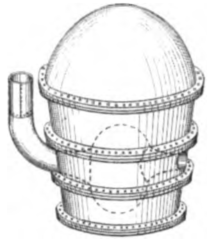


Fig. 44. Watt's Boiler.
Hooped wooden shell
with copper tube.
Length 12' 0" Diam. 5' 0"

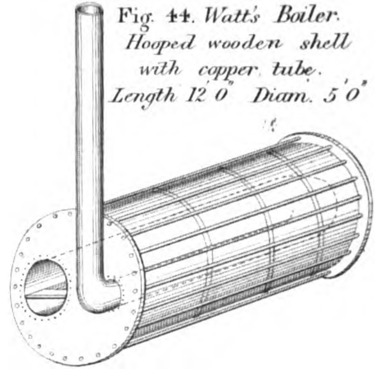


Fig. 45. Brindley's Boiler.
Stone chamber
with copper tube.
Length 12' 0" Diam. 5' 0"

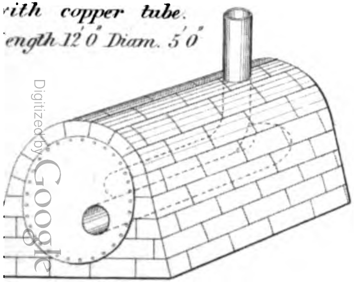


Fig. 46. Trevithick's Boiler.
Cast-iron shell
with wrought-iron tube.
Length 9' 0" Diam. 4' 6"

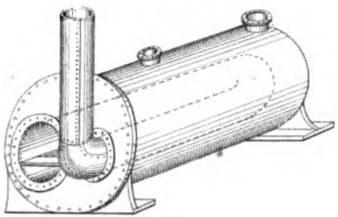


Fig. 47. Woolf's Boiler. Cast-iron.

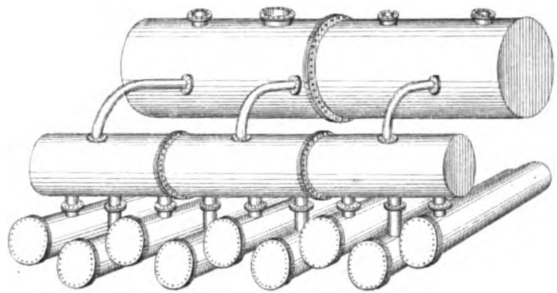


Plate 52.

BOILER EXPLOSIONS.

Fig. 48. Wagon Boiler with flat sides. Length 22'0" Width 5'0" Height 7'0"

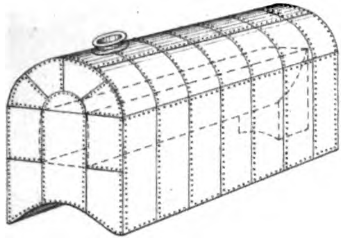


Fig. 49. Wagon Boiler with concave sides. Length 22'0" Width 7'0" Height 7'0"

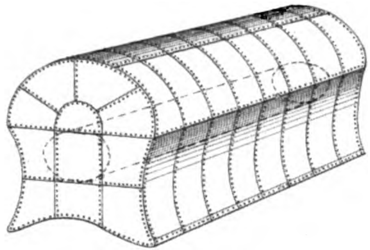


Fig. 52. Spherical Boiler. Diam. 12'0"

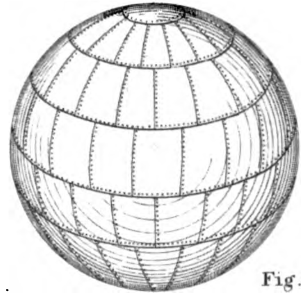


Fig. 53. Boiler with spherical top and dished bottom. Diam. 12'0"

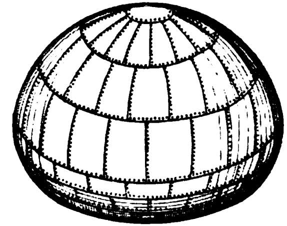


Fig. 50. Wagon Boiler with rounded ends. Length 26'0" Height 8'0"

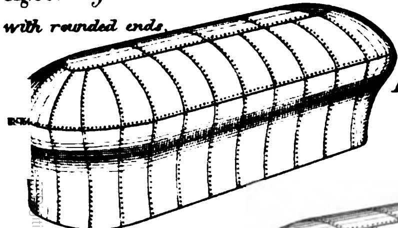


Fig. 51. Wagon Boiler with convex bottom. Length 26'0" Height 9'0"

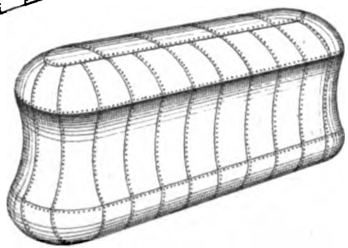


Fig. 54. Haystack or Balloon Boiler with flat sides and bottom. Diam. 14'0"

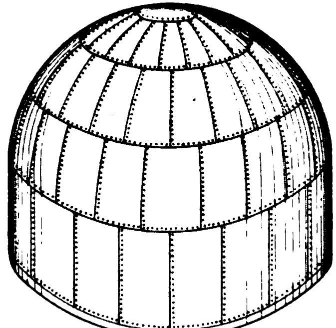
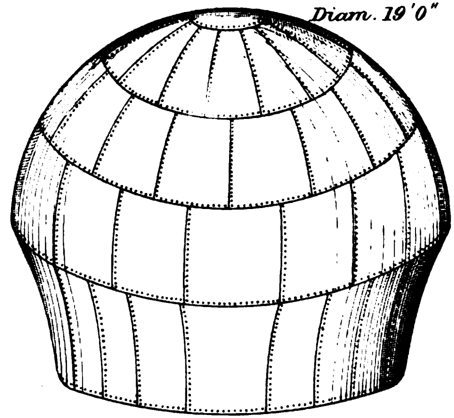


Fig. 55. Haystack or Balloon Boiler with concave sides and bottom. Diam. 19'0"



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BOILER EXPLOSIONS.

Plate 53.

Fig. 56. *Haystack or Balloon Boiler with internal fireplace and internal spiral flue. Diam. 12′ 0″*

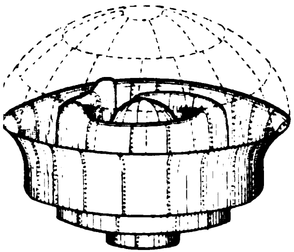


Fig. 57. *Plain Cylindrical Boiler with flat ends and straight seams. Length 20′ 0″ Diam. 6′ 0″*

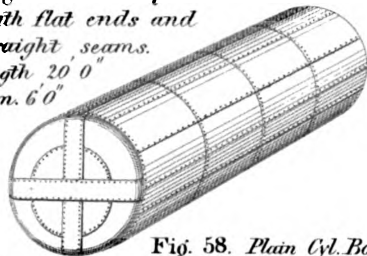


Fig. 58. *Plain Cyl. Boiler with spherical ends and crossed seams. Length 30′ 0″ Diam. 7′ 0″*

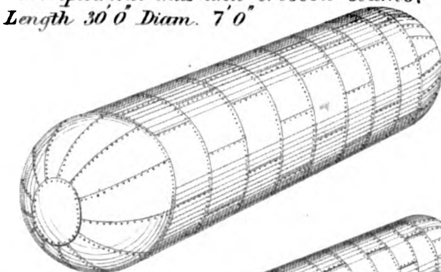


Fig. 59. *Annular Boiler. Diam. of circle 25′ 0″ outside. 15′ 0″ inside.*

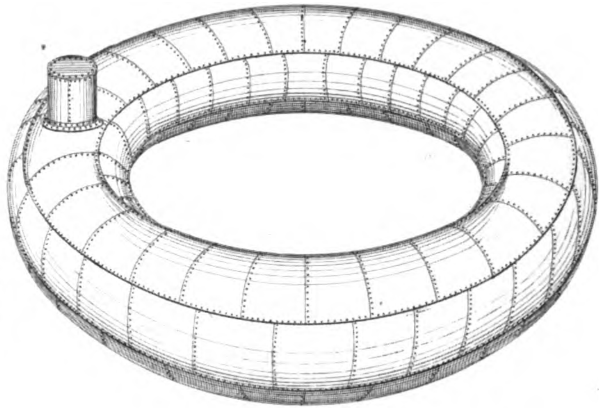


Fig. 60. *Retort Boiler. Retorts 1′ 5″ diam., 9′ 0″ length.*

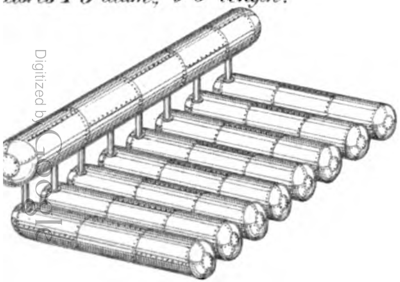


Fig. 61. *Elephant or French Boiler. Length 24′ 0″ Diams 4′ 0″ and 2′ 3″*

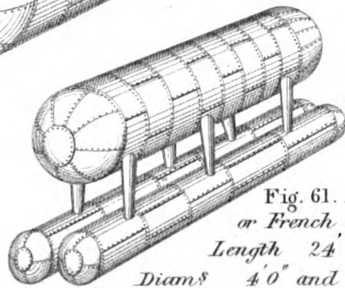
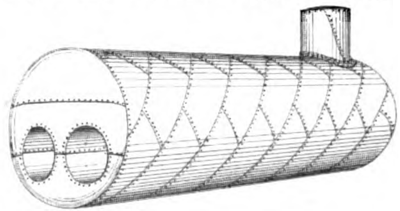


Fig. 62. *Lancashire Boiler with diagonal seams. Length 26′ 0″ Diam. 7′ 0″ Tubes 2′ 6″ diam.*



BOILER EXPLOSIONS.

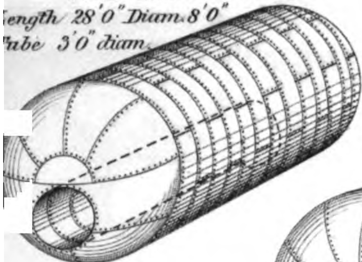


Fig. 63. *Externally fired Boiler with internal tube.* Length 28′ 0″ Diam. 8′ 0″ Tube 3′ 0″ diam.

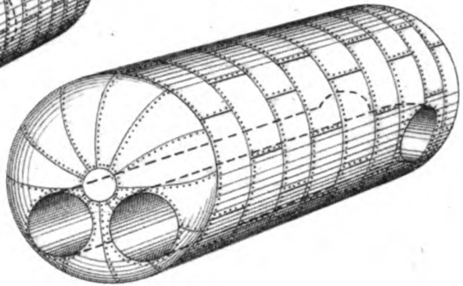


Fig. 64. *Externally fired Boiler with internal tubes.* Length 28′ 0″ Diam. 9′ 0″ Tubes 2′ 6″ diam.

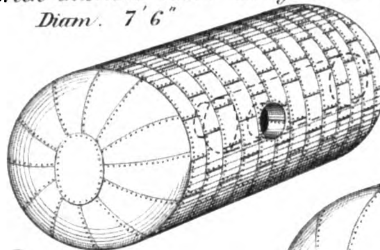


Fig. 65. *Externally fired Boiler with internal tube.* Length 26′ 0″ Diam. 7′ 6″

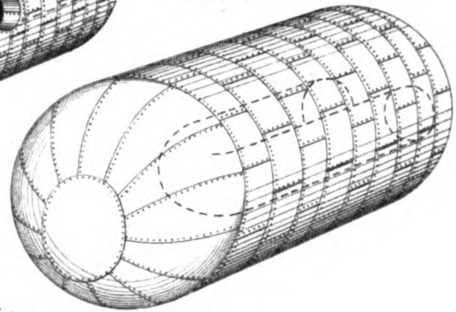


Fig. 66. *British-Tube Boiler, externally fired.* Length 26′ 0″ Diam. 10′ 0″ Tube 2′ 6″ diam.

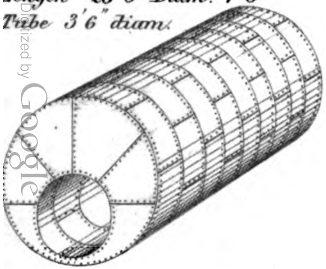


Fig. 67. *Cornish Boiler.* Length 28′ 0″ Diam. 7′ 0″ Tube 3′ 6″ diam.

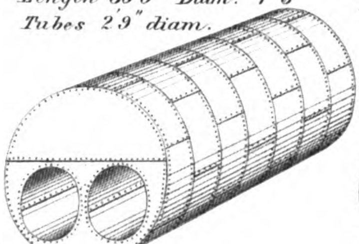


Fig. 68. *Lancashire Boiler.* Length 30′ 0″ Diam. 7′ 6″ Tubes 2′ 9″ diam.

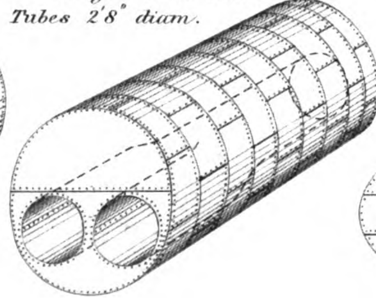


Fig. 69. *Breeches-Tube Boiler.* Length 30′ 0″ Diam. 8′ 0″ Tubes 2′ 8″ diam.

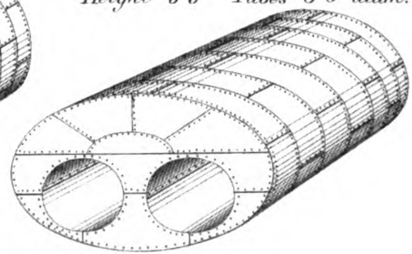


Fig. 70. *Oval Lancashire Boiler.* Length 16′ 0″ Width 10′ 0″ Height 6′ 6″ Tubes 3′ 0″ diam.

Plate 55.

BOILER EXPLOSIONS.

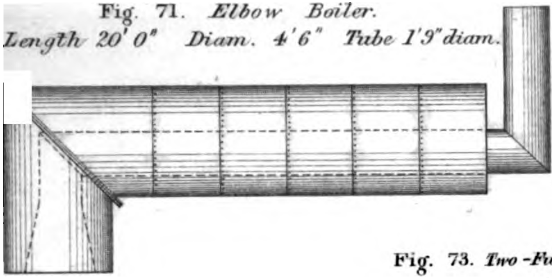


Fig. 71. *Elbow Boiler.*
Length 20' 0" Diam. 4' 6" Tube 1' 9" diam.

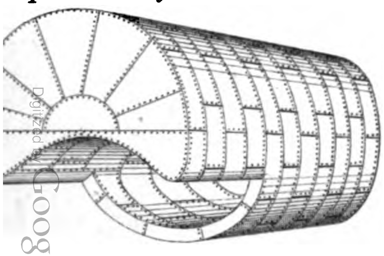


Fig. 72. *Butterley Boiler.*
Length 26' 0" Diam. 9' 0"
ireplace 8' 6" length. Tube 3' 6" diam.

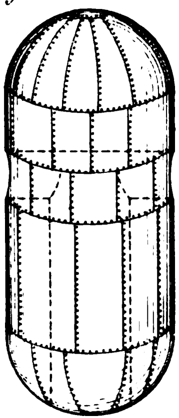


Fig. 73. *Two-Furnace*
Upright Boiler.
Height 16' 6" Diam. 7' 0"

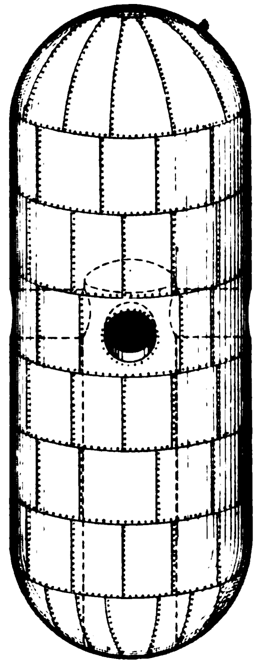


Fig. 74. *Four-Furnace*
Upright Boiler.
Height 28' 0" Diam. 10' 0"

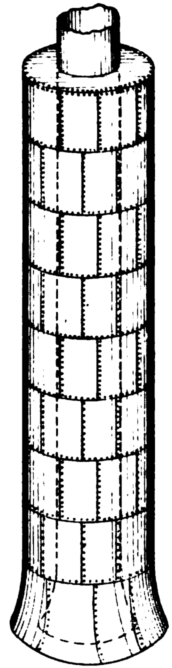


Fig. 75. *Chimney Boiler.*
Height 26' 0" Diam. 5' 6"
Tube 3' 0" diam.

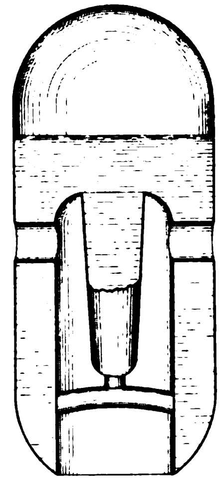


Fig. 76. *Internally fired*
Upright Boiler.
Height 20' 0" Diam. 9' 0"

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IRON COLUMNS OF COTTON MILL.

Plate 56.

Fig. 1. *Longitudinal Section of Cotton Mill.*

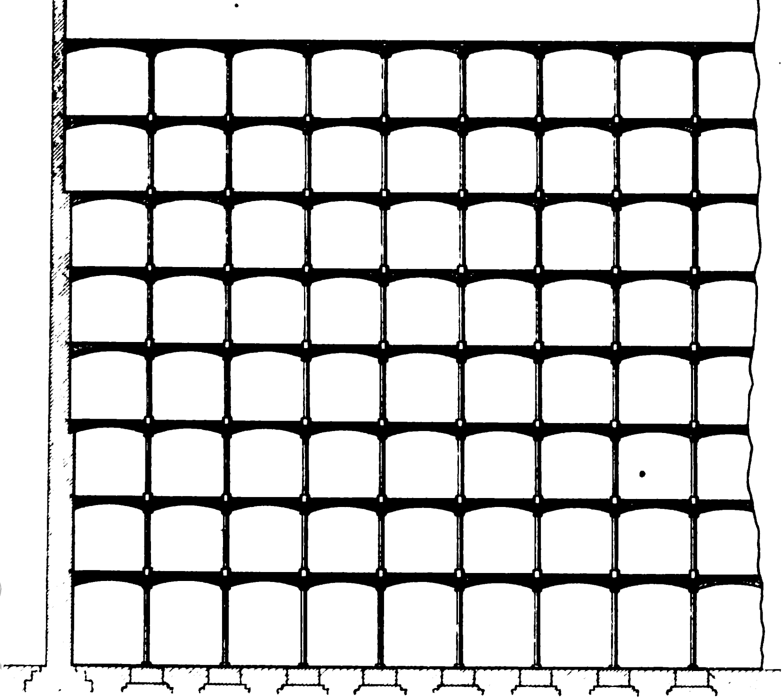
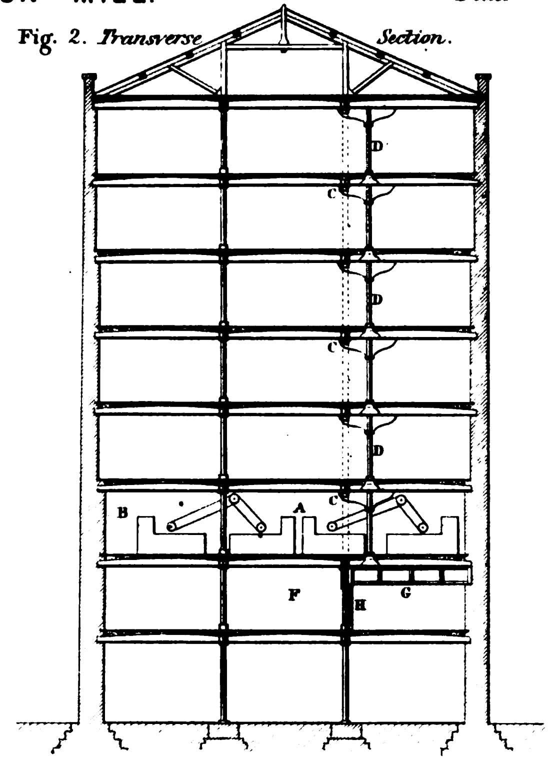


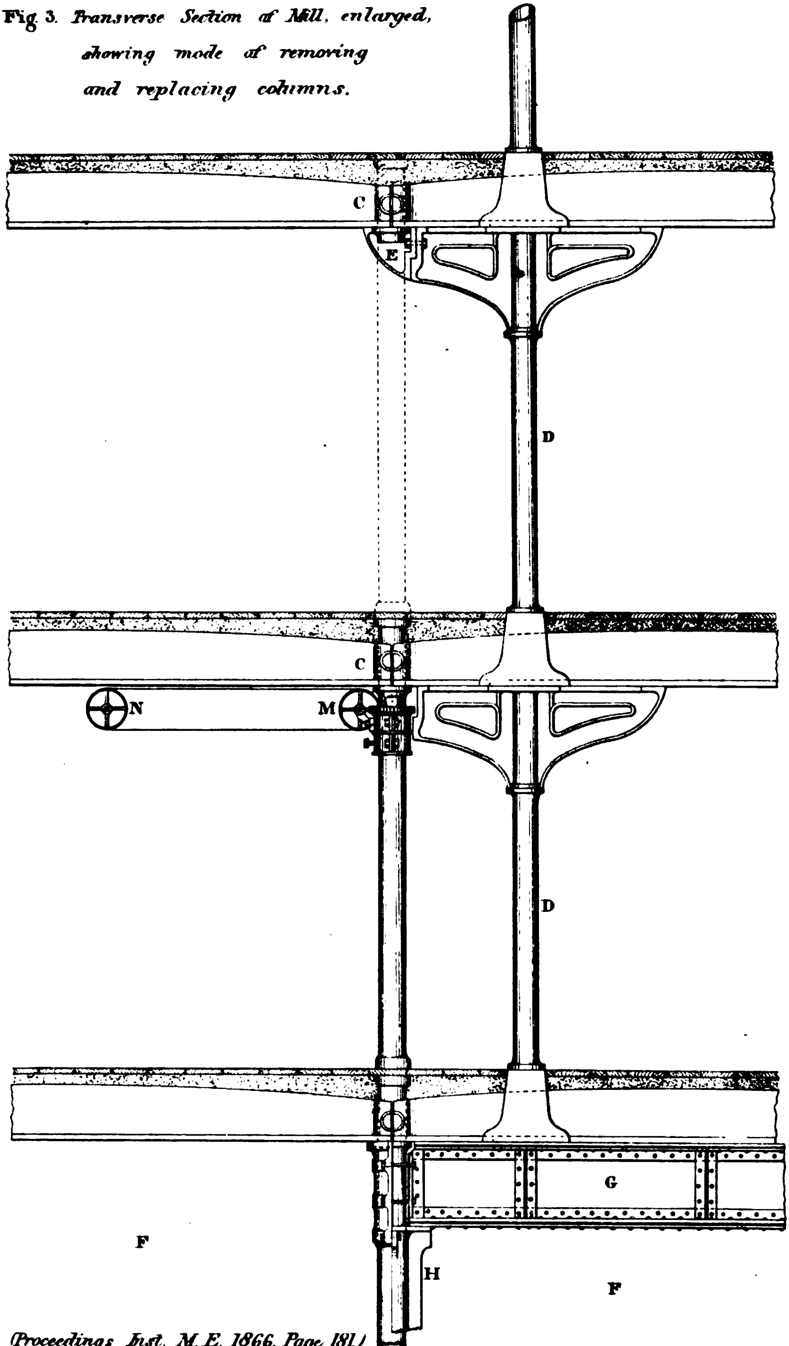
Fig. 2. *Transverse Section.*



(*Proceedings Inst. M.E. 1866. Page 181*) *Scale* $1/300^{th}$

10 5 0 10 20 30 40 50 60 70 80 Feet.

Fig. 3. *Transverse Section of Mill, enlarged, showing mode of removing and replacing columns.*



(Proceedings Inst. M.E. 1866. Page 181)

Scale 1/50 th 0 1 2 3 4 5 6 7 8 9 10 Feet.

Fig. 4. *Elevation of Apparatus for cutting away Columns.*

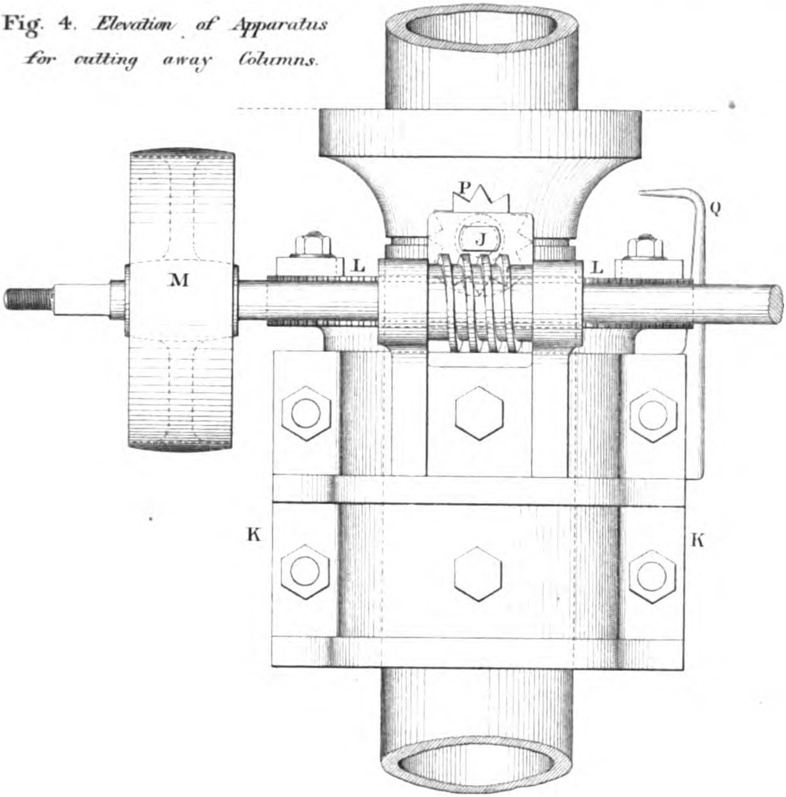
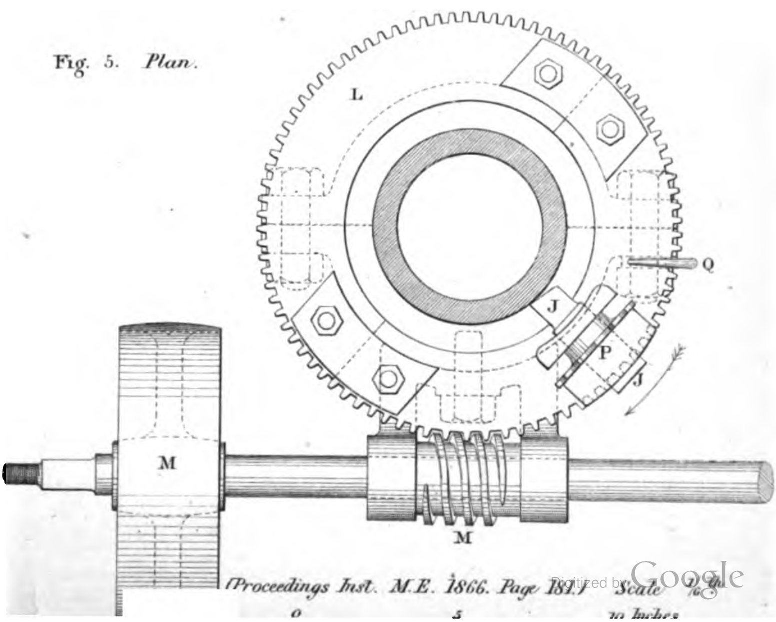


Fig. 5. *Plan.*



 Scale 1/6th

0 5 10 Inches

Fig. 1. *Vertical Section of Casting Mould.*

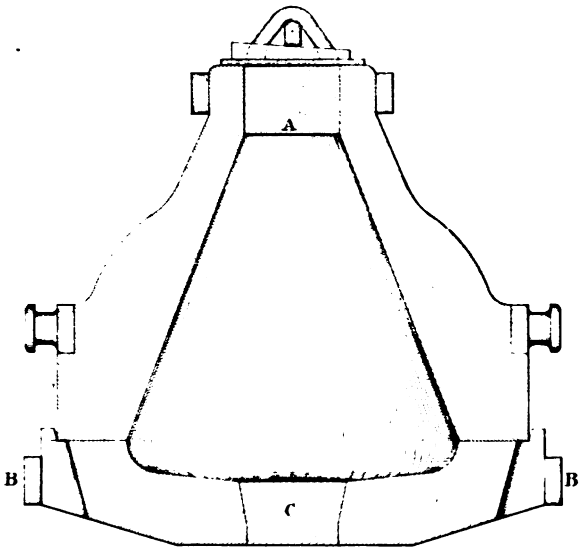
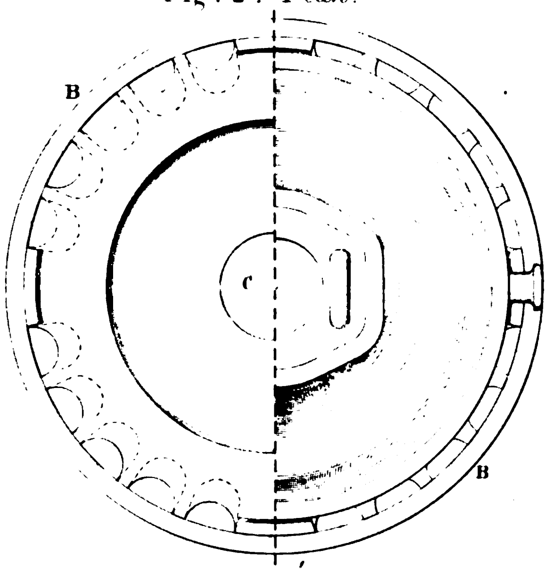


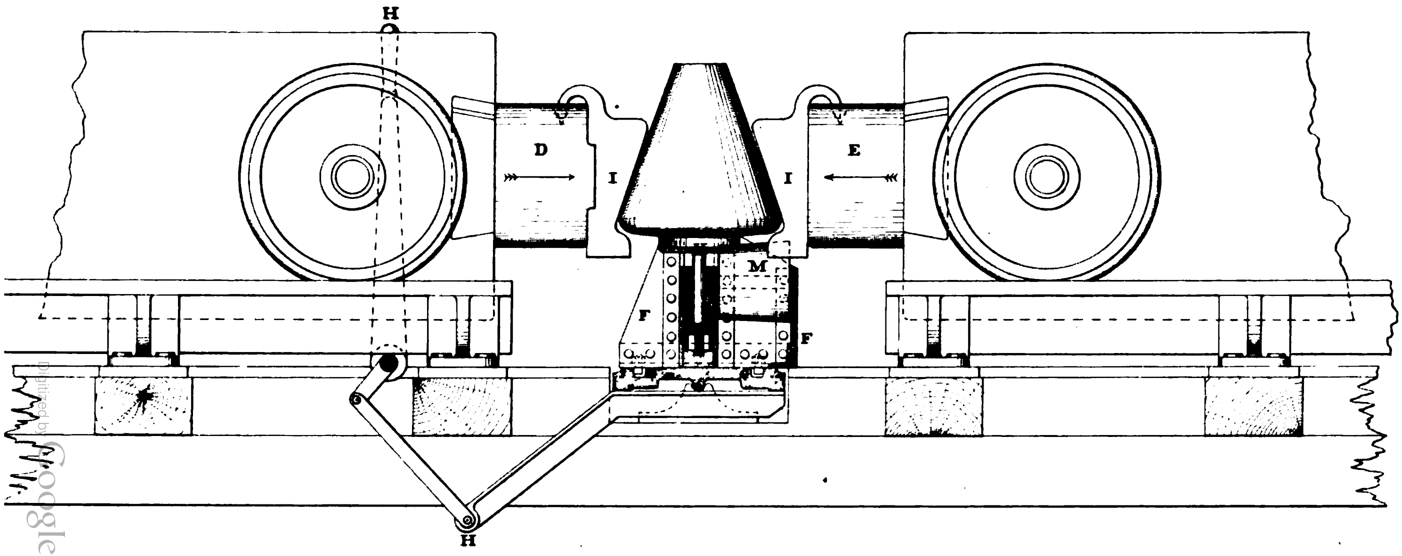
Fig. 2. *Plan.*



(Proceedings Inst. M. E. 1866. Page 186.) *Scale 1/12th.*

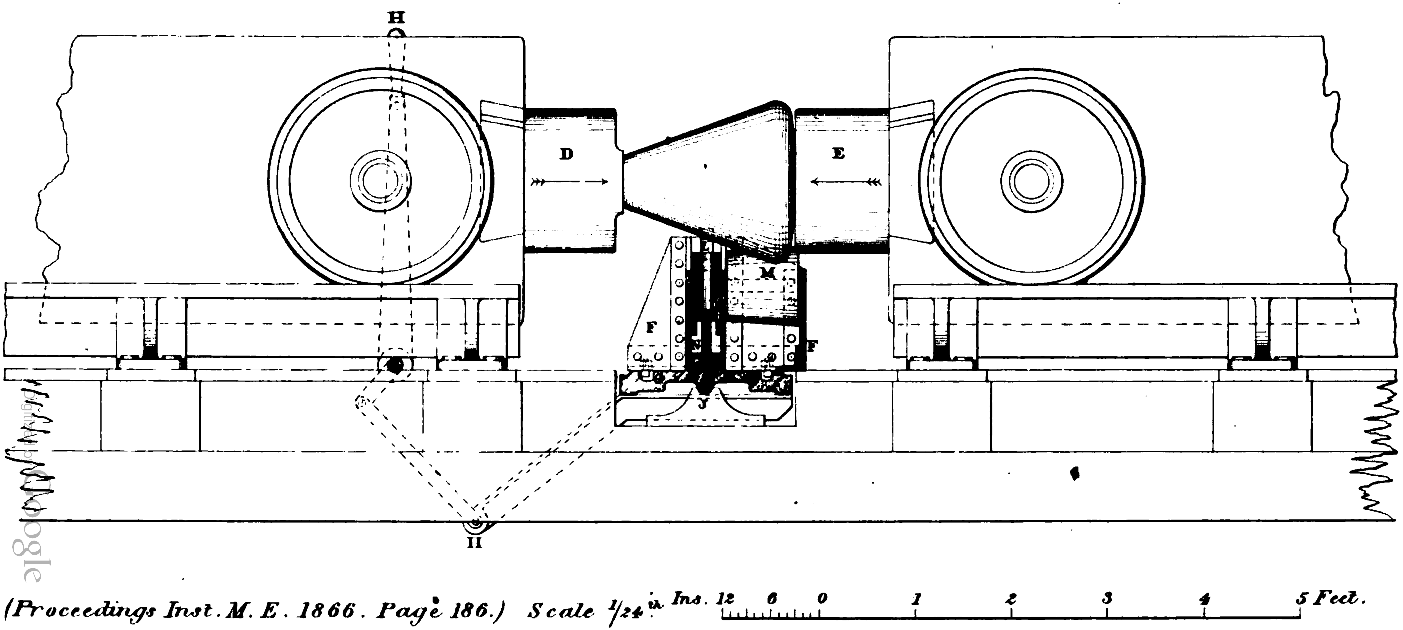
10 5 0 10 20 30 Inches.

Fig. 3. *Side Elevation of Horizontal Duplex Hammer, hammering Bloom laterally.*



(Proceedings Inst. M. E. 1866. Page 186.) *Scale 1/24th*

Fig. 4. *Side Elevation of Horizontal Duplex Hammer, hammering Bloom endways.*



(Proceedings Inst. M. E. 1866. Page 186.) *Scale* 1/24th

Fig. 5. *Transverse Section of Horizontal Duplex Hammer, hammering Bloom laterally.*

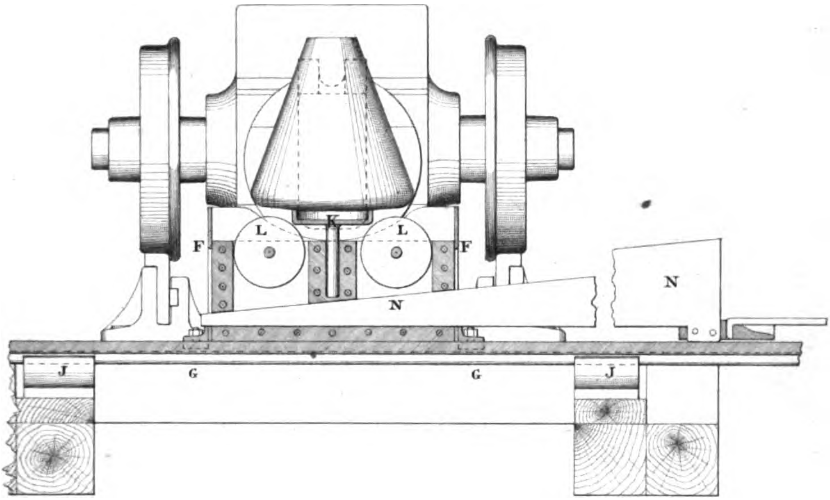
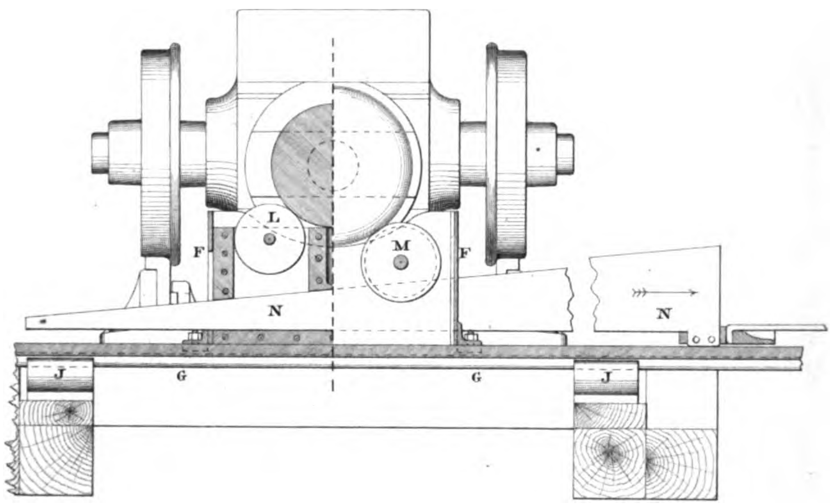


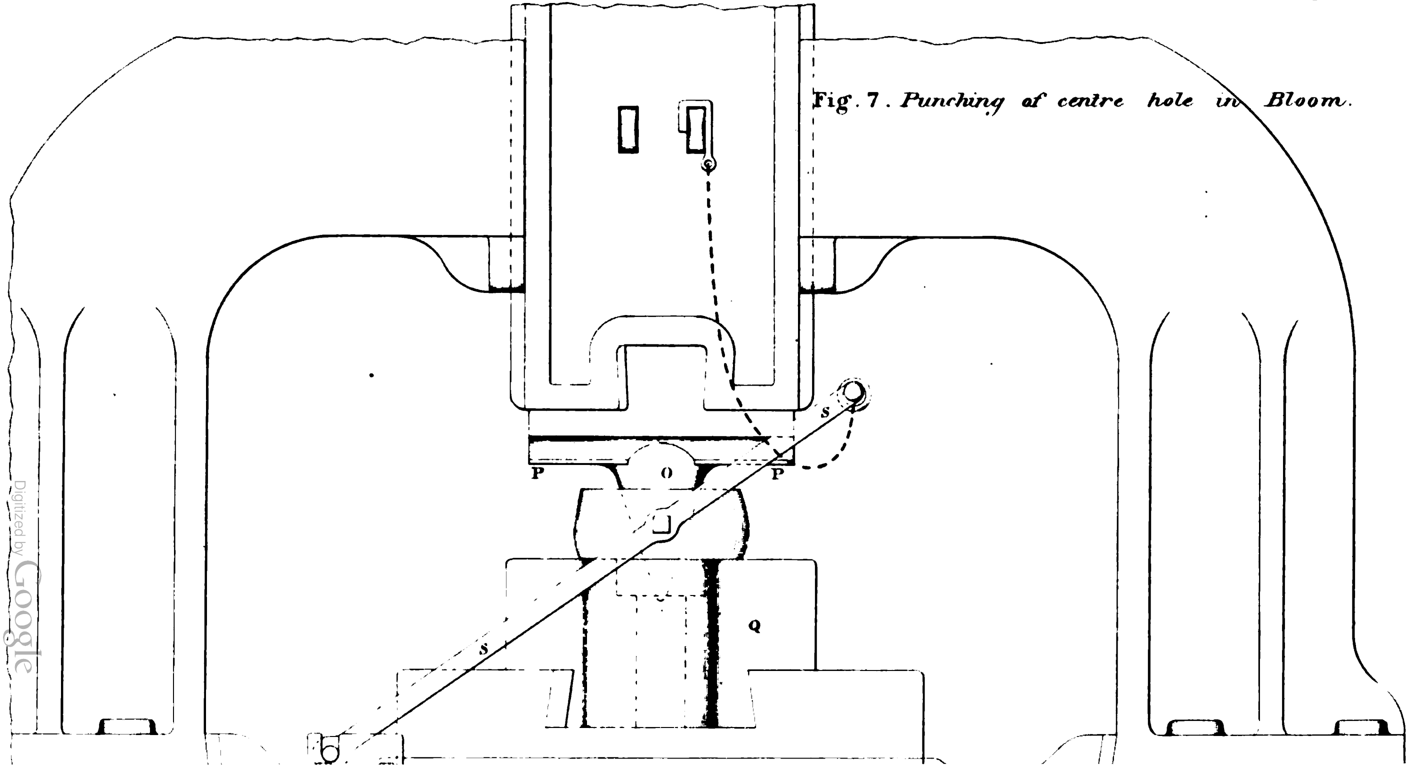
Fig. 6. *Transverse Section of Horizontal Duplex Hammer, hammering Bloom endways.*



(Proceedings Inst. M.E. 1866. Page 186.) *Scale 1/24th*

Ins. 12 6 0 1 2 3 4 5 Feet.

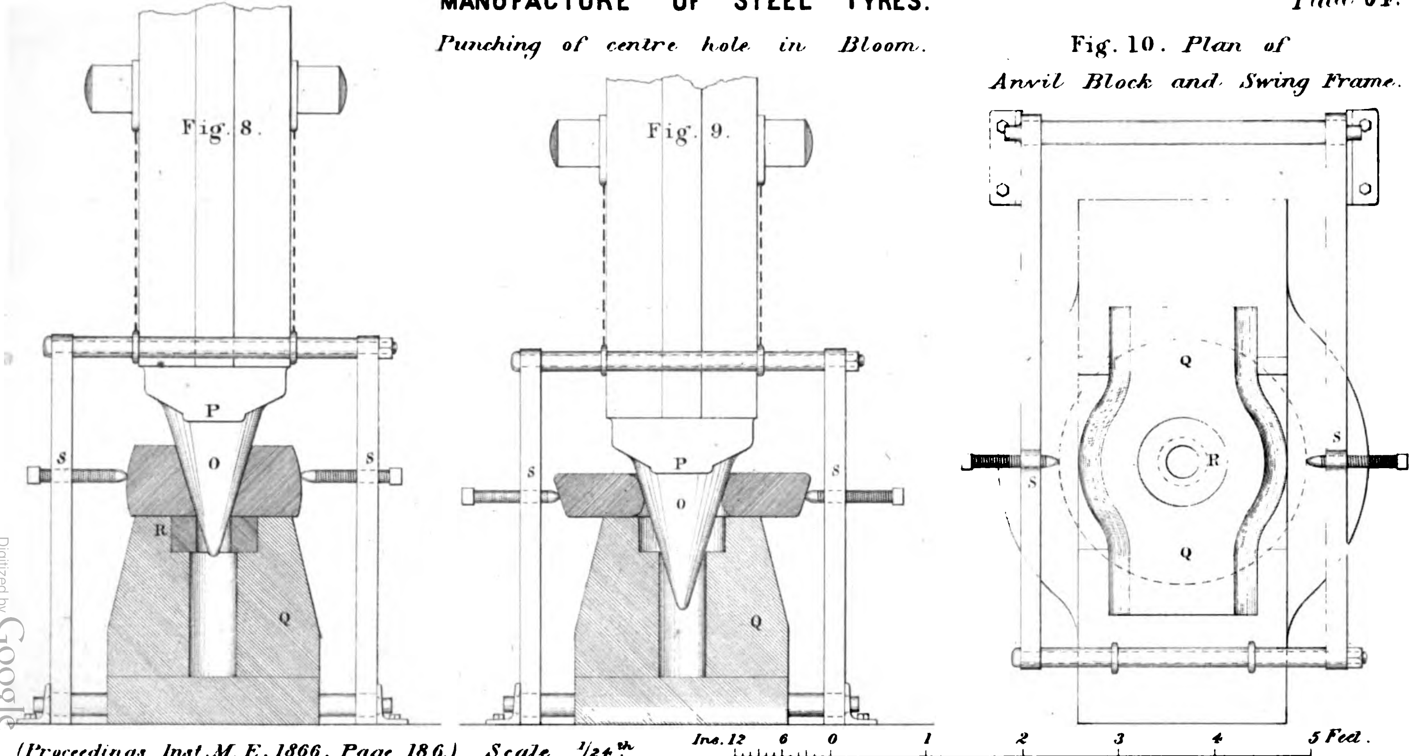
Fig. 7. Punching of centre hole in Bloom.



MANUFACTURE OF STEEL TYRES.

Punching of centre hole in Bloom.

Fig. 10. Plan of Anvil Block and Swing Frame.



(Proceedings Inst. M. E. 1866. Page 186.) Scale 1/24th

MANUFACTURE OF STEEL TYRES.

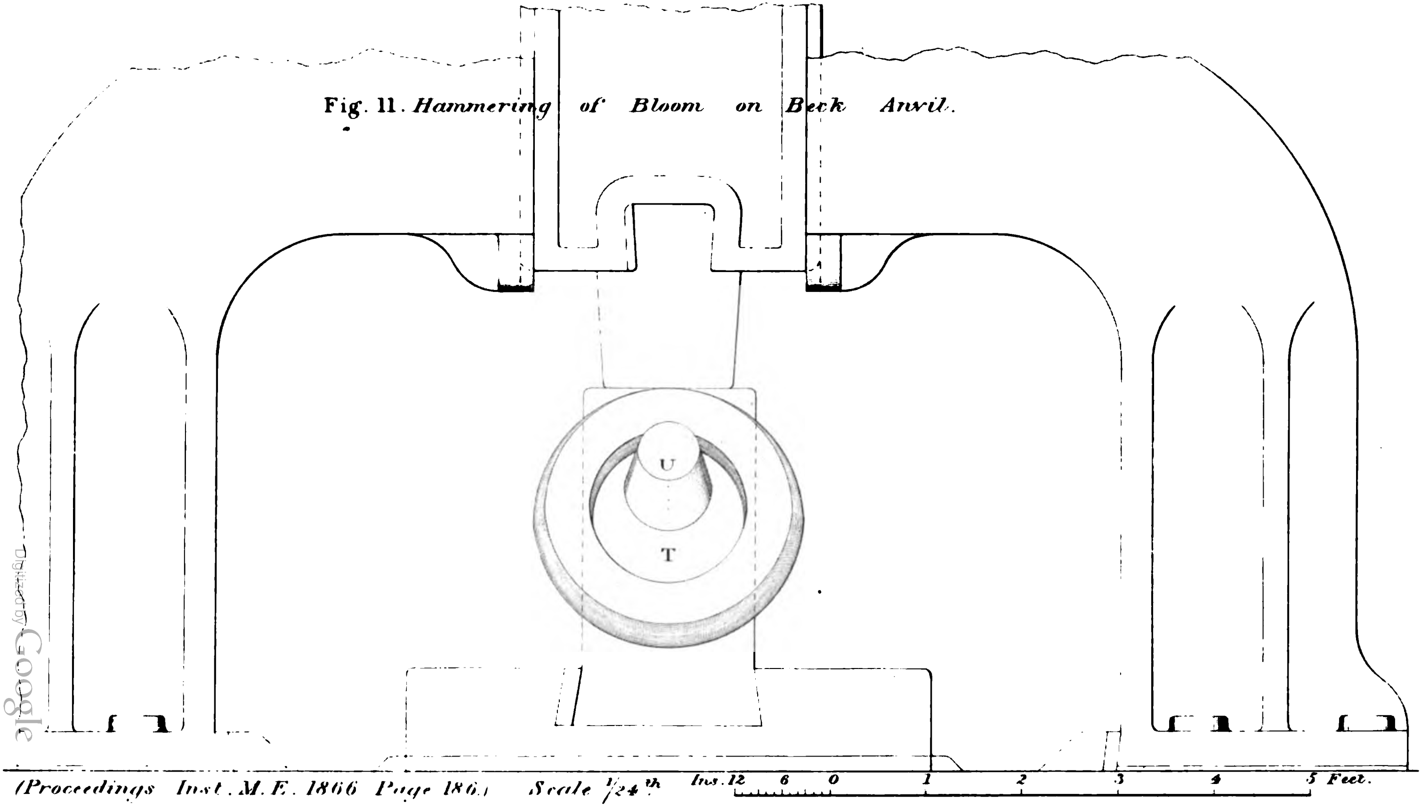


Fig. 11. *Hammering of Bloom on Beck Anvil.*

(Proceedings Inst. M. E. 1866 Page 186.) *Scale 1/24th.*

MANUFACTURE OF STEEL TYRES.

Hammering of Bloom on Beck Anvil.

Fig. 12.

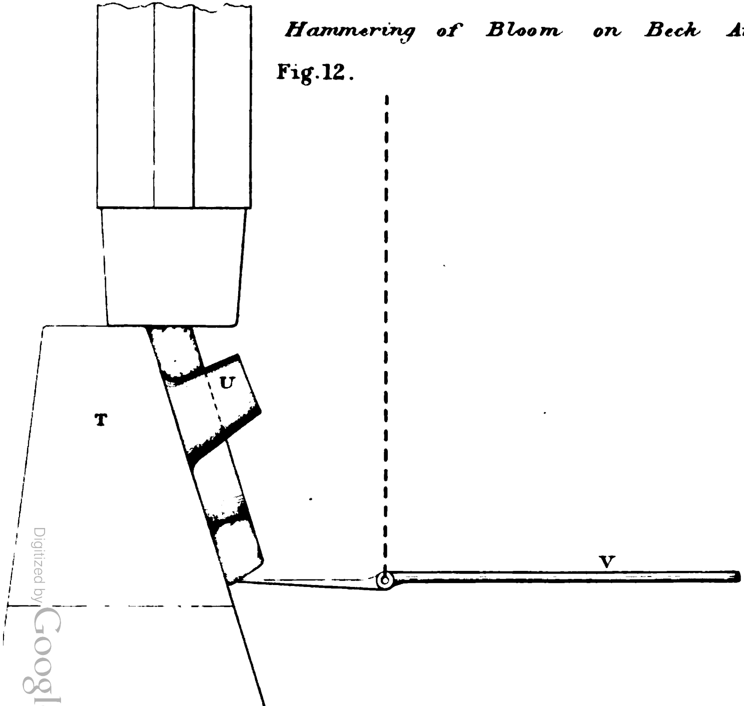
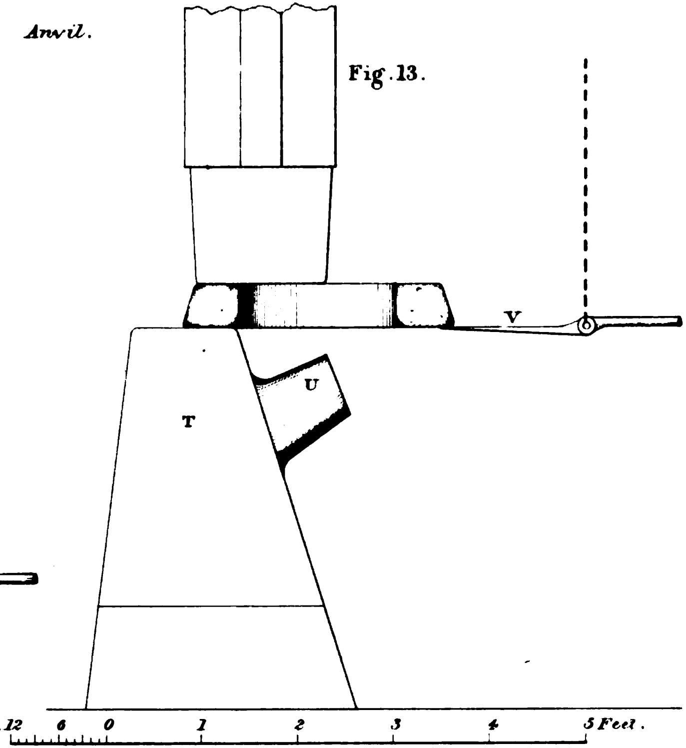


Fig. 13.



(Proceedings Inst. M.E. 1866. Page 186.) *Scale 1/24th.*

MANUFACTURE OF STEEL TYRES.

Fig. 14. Steel Ingot from Casting Mould.

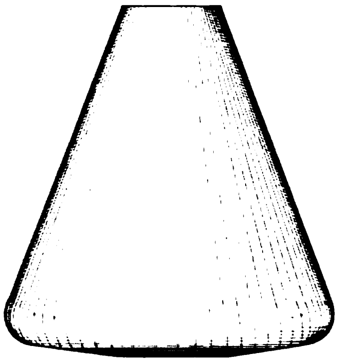


Fig. 15. Hammered Bloom from Horizontal Duplex Hammer.

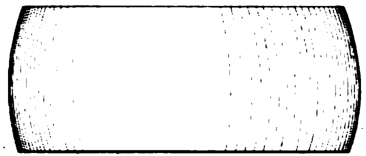


Fig. 16. Centre hole punched.

Fig. 17. After working under Punching Hammer.

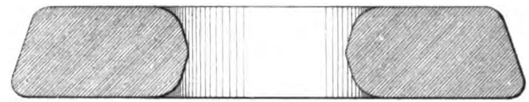


Fig. 18. After hammering on Beck Anvil.

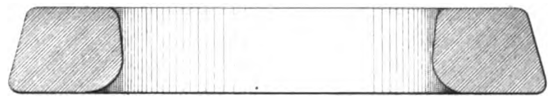
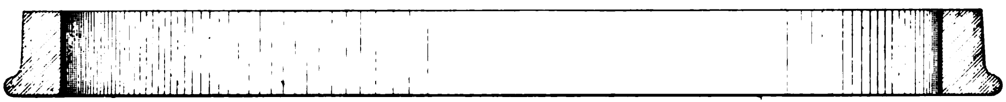
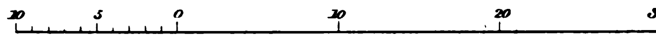


Fig. 19. Finished Tyre from Circular Rolling Mill.



(Proceedings Inst. M.E. 1866. Page 186.) Scale $\frac{1}{12}$th



COTTON MACHINERY.

Fig. 1. *Arkwright's Spinning Machine. 1769.*
Scale 1/10 th.

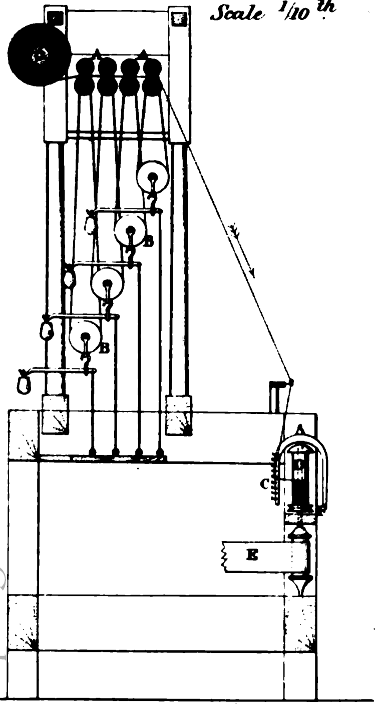
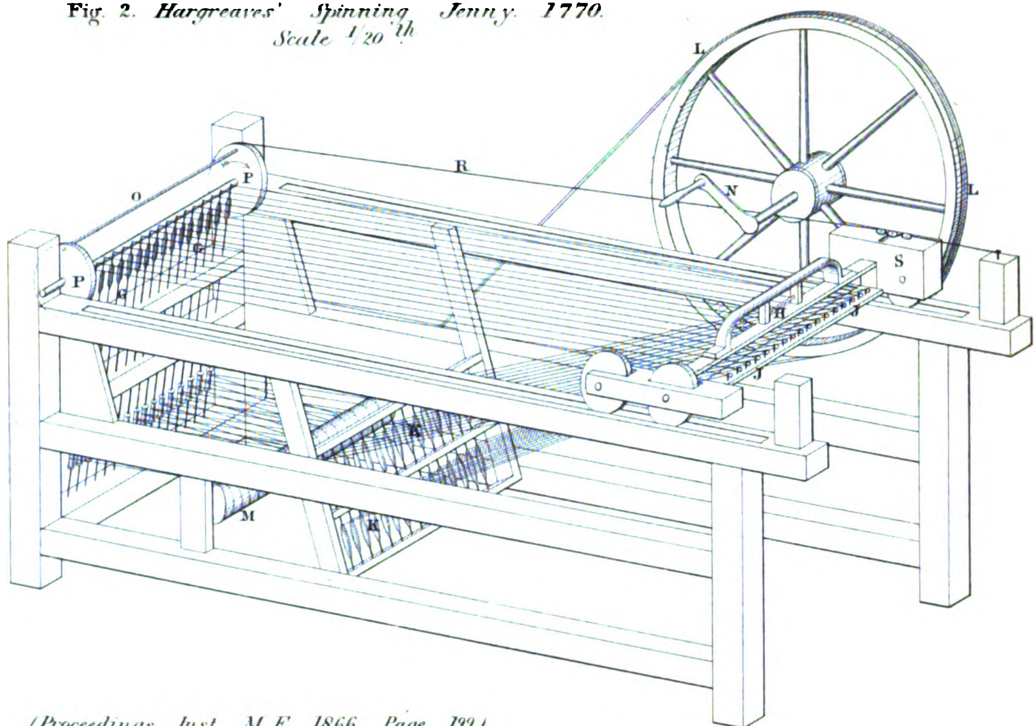


Fig. 2. *Hargreaves' Spinning Jenny. 1770.*
Scale 1/20 th.



(Proceedings Inst. M.E. 1866. Page 199.)

COTTON MACHINERY. *Plate 69.*

Fig. 4. *Plan of Picker Cylinder.*

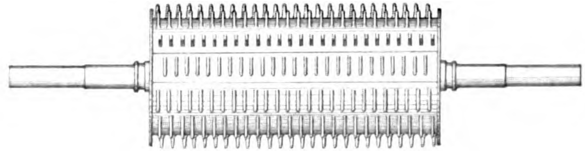
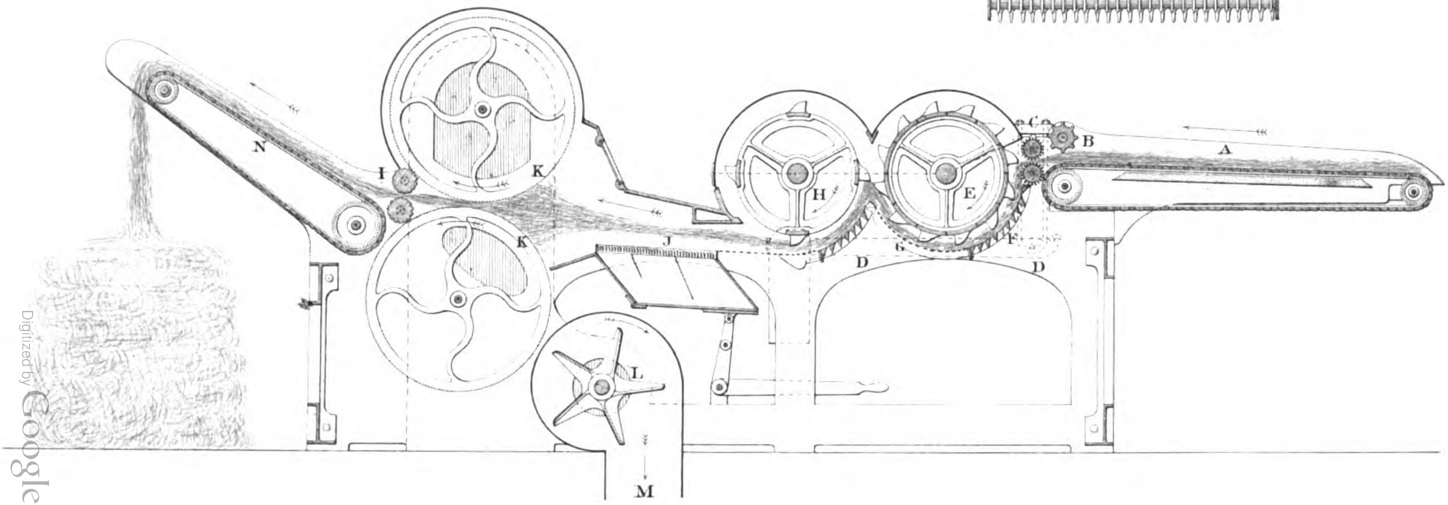


Fig. 3. *Cotton Opener. 1866.*



Scale 1/24th.

12 6 0 1 2 3 4 5 6 7 8 9 10 *Feet.*

(Proceedings Inst. M.E. 1866. Page 199.)

COTTON MACHINERY.

Plate 70.

Fig. 6. *Plan of Beater.*

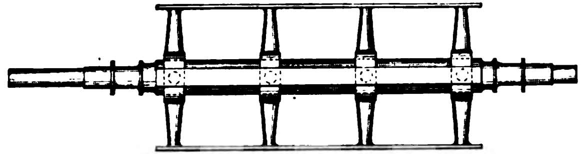
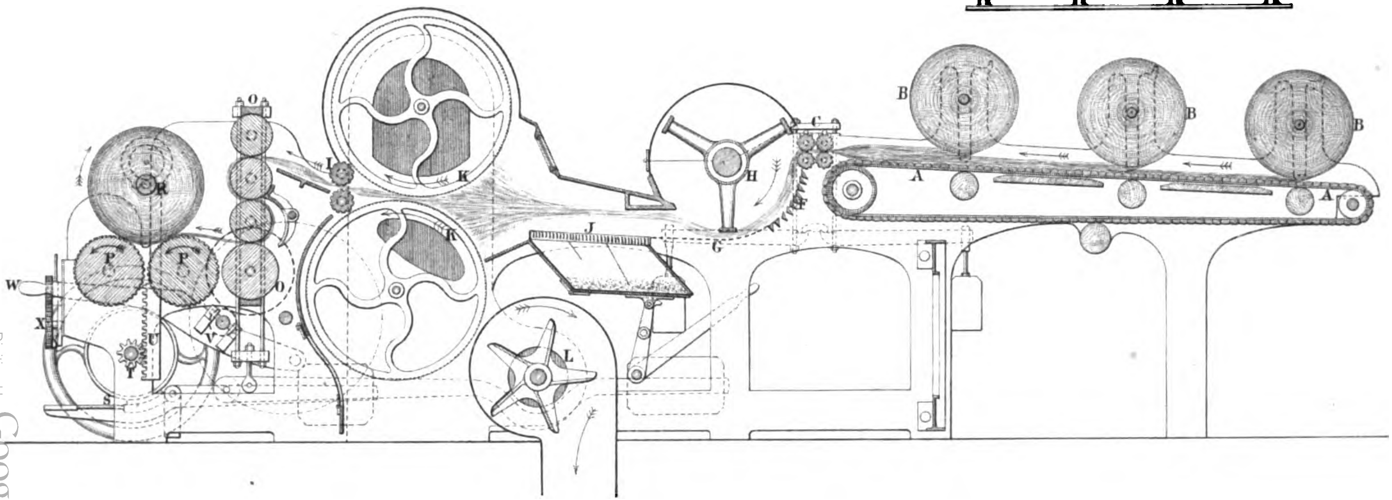


Fig. 5. *Single Scutcher and Lap Machine. 1866.*



Scale 1/24th Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M. E. 1866. Page 199.)

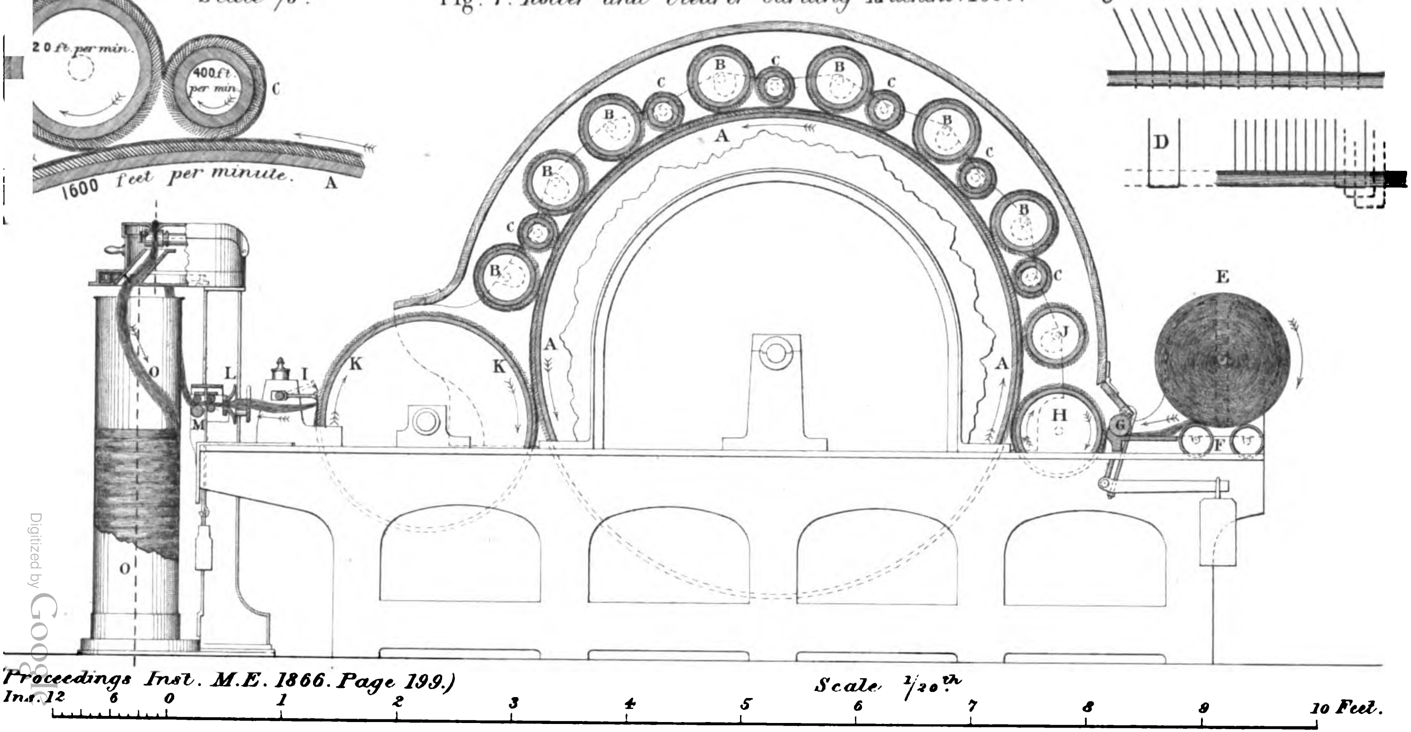
COTTON MACHINERY.

Plate 71.

Fig. 8. *Roller and Clearer.* Scale 1/8th.

Fig. 7. *Roller and Clearer Carding Machine.* 1866.

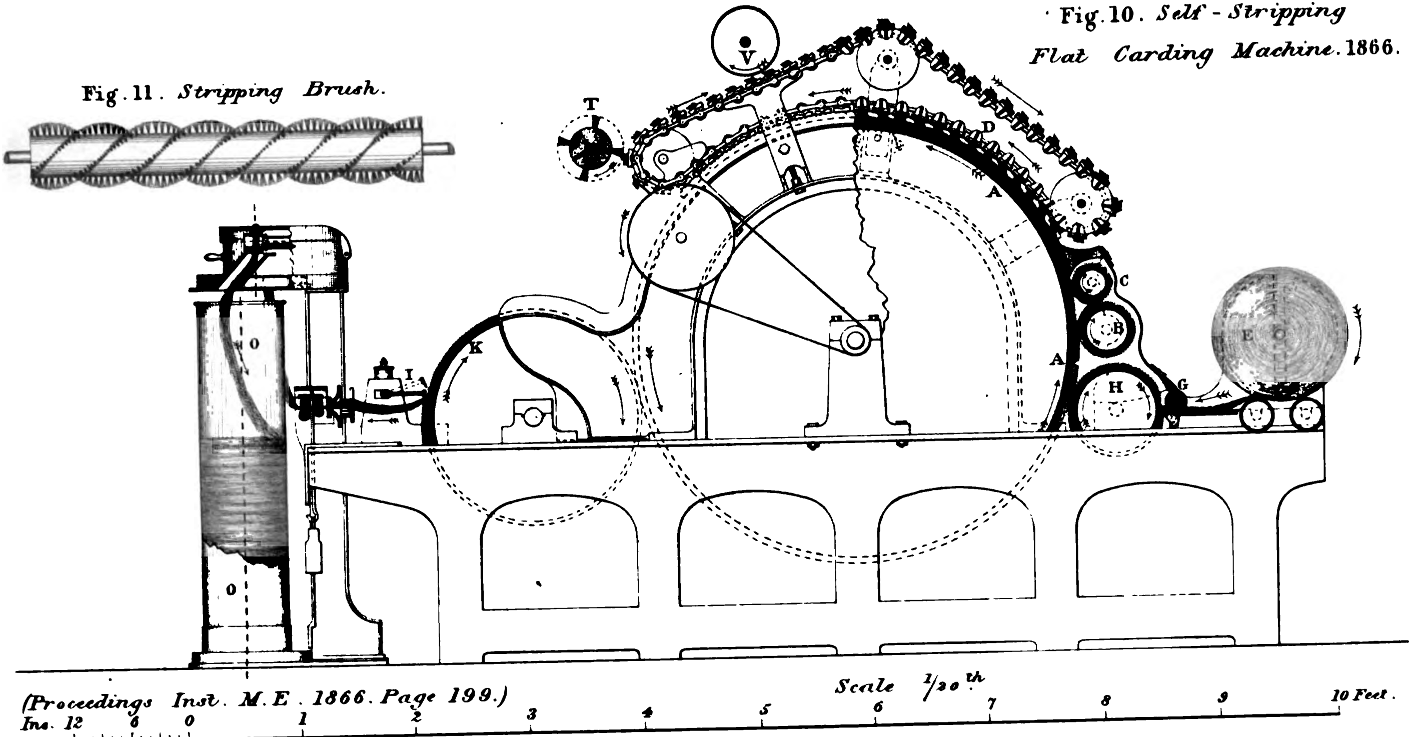
Fig. 9. *Card. Full size.*



COTTON MACHINERY.

Fig. 11. Stripping Brush.

Fig. 10. Self-Stripping Flat Carding Machine. 1866.



COTTON MACHINERY. *Plate 73.*

Fig. 12. Self-Stripping Flat Carding Machine.

Enlarged View of Cards.

Scale 1/10th.

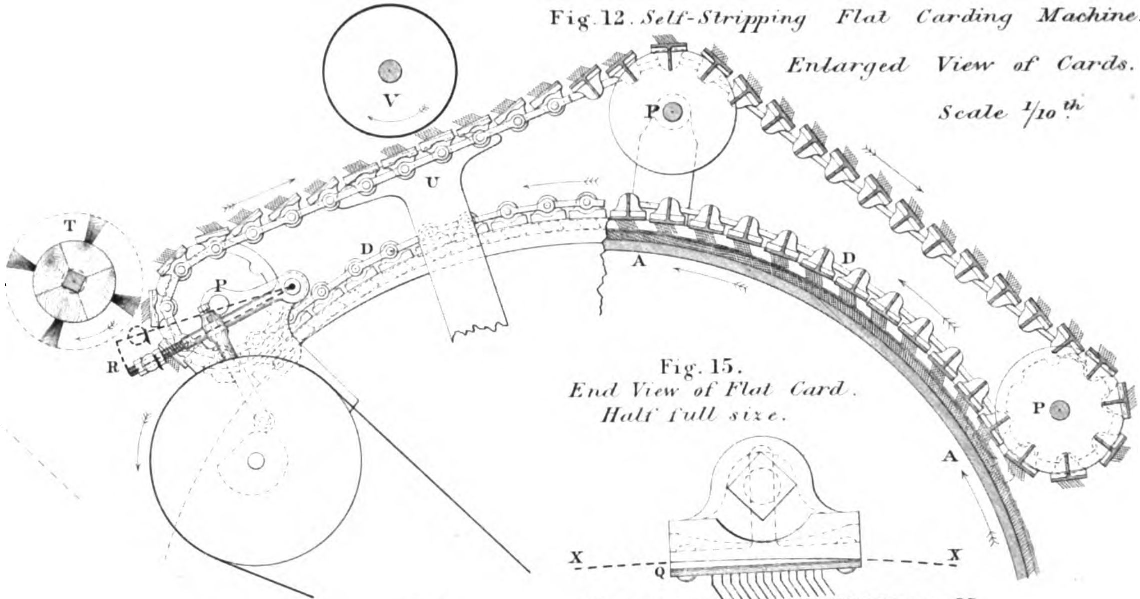


Fig. 13.

Vibrating Comb for stripping the Cards.

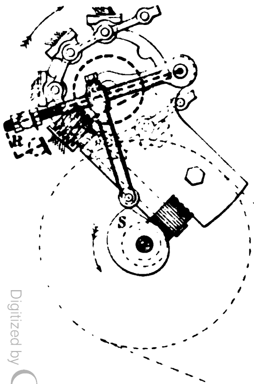


Fig. 15.
End View of Flat Card.
Half full size.

Fig. 14. ***Front View of Flat Card.*** ***Scale 1/5th.***

Scale 1/10th. 0 10 20 30 *Inches*

Fig. 16. *Drawing Frame. 1866.*

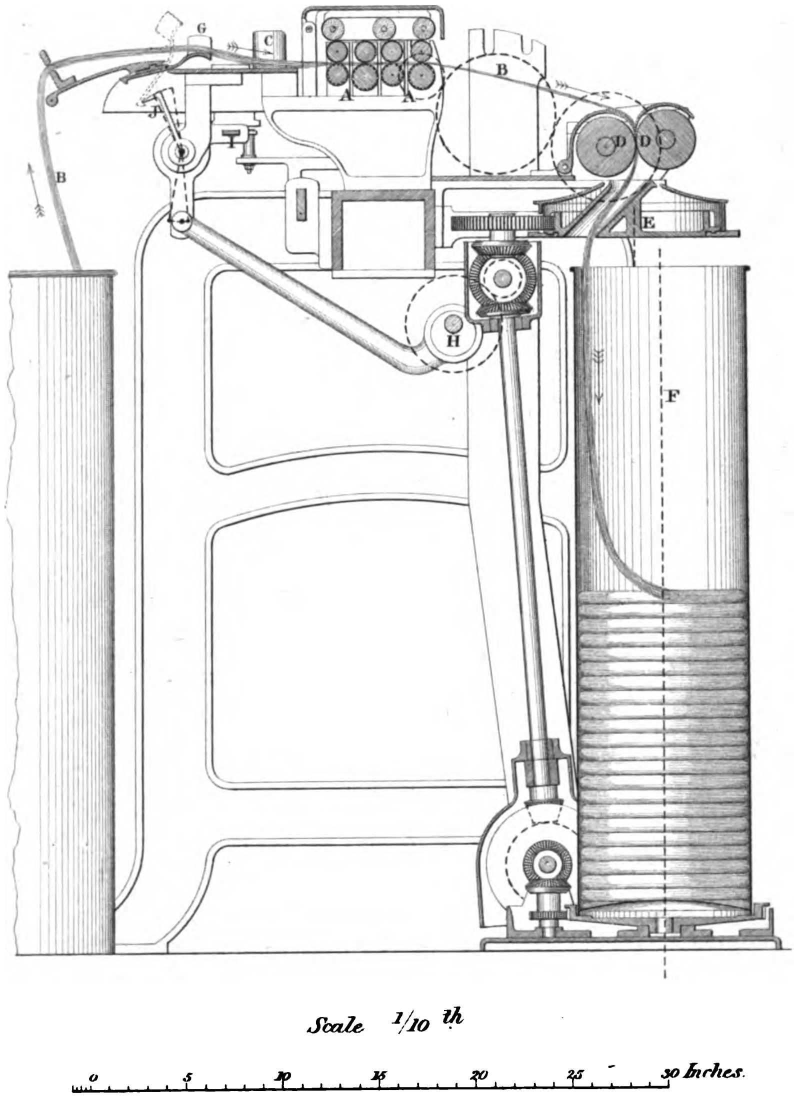
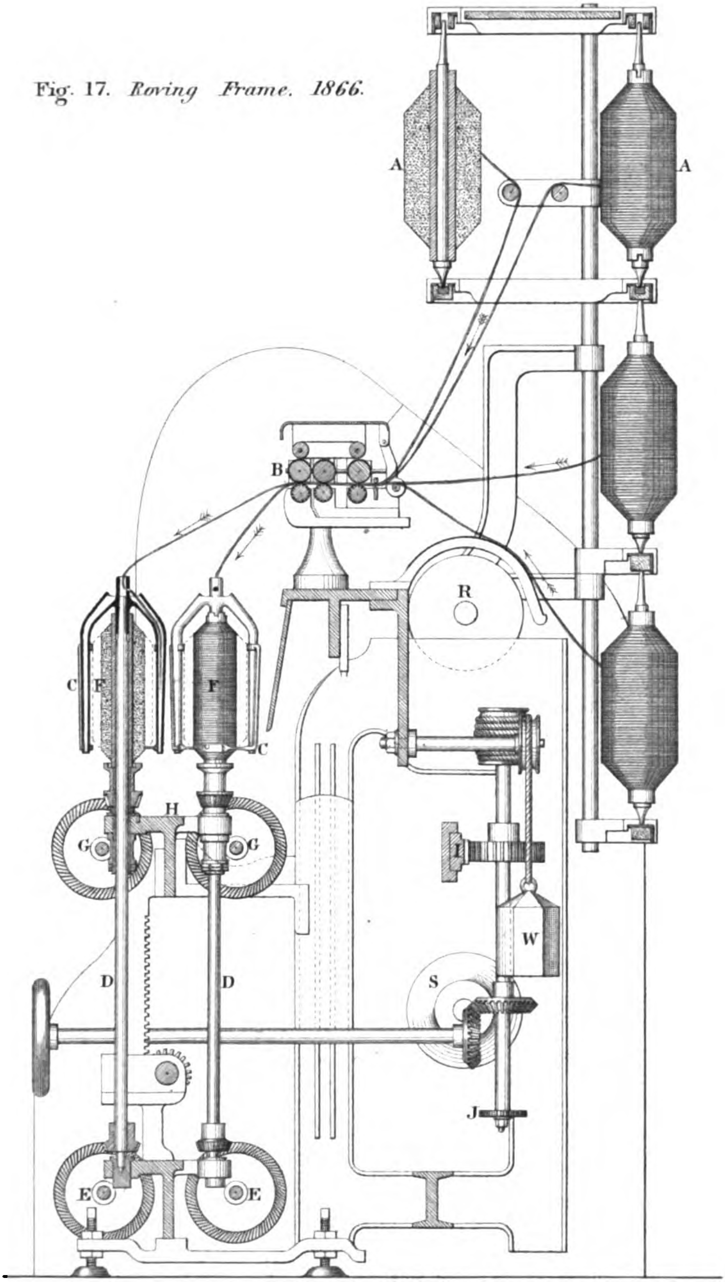


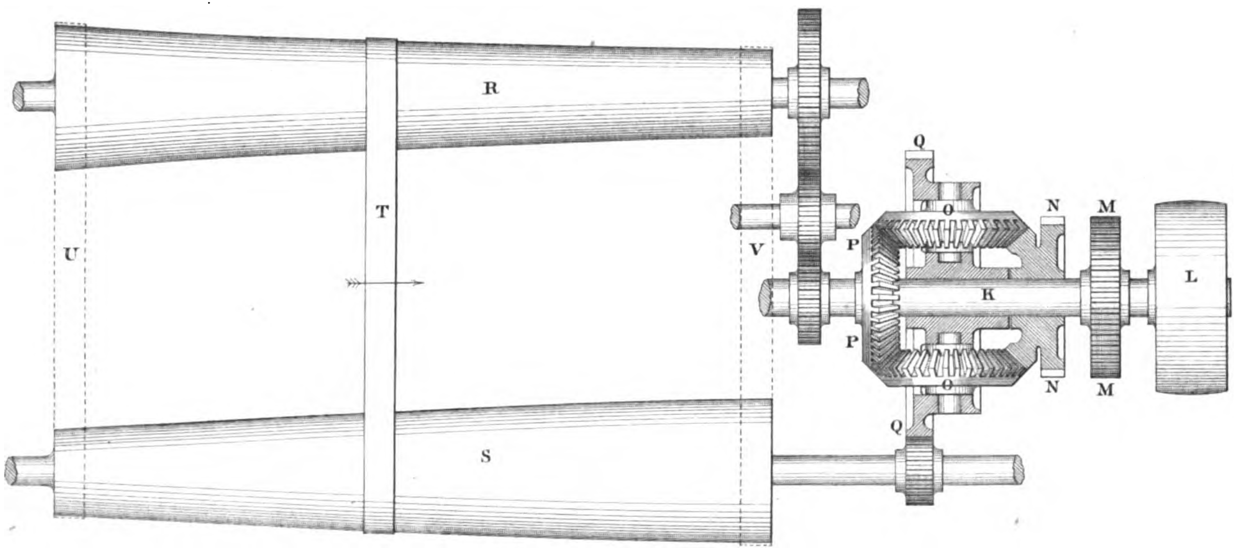
Fig. 17. *Roving Frame. 1866.*



(Proceedings Inst. M.E. 1866. Page 139.) *Scale 1/10th*

0 5 10 15 20 25 30 Inches.

Fig. 18. *Houldsworth's Differential Motion. 1826.*



(Proceedings Inst. M. E. 1866. Page 199.) Scale 1/8 th. 0 5 10 15 20 25 30 Inches

Eaton's Backing - Off Motion. 1818.

Fig. 19. *Side Elevation.*

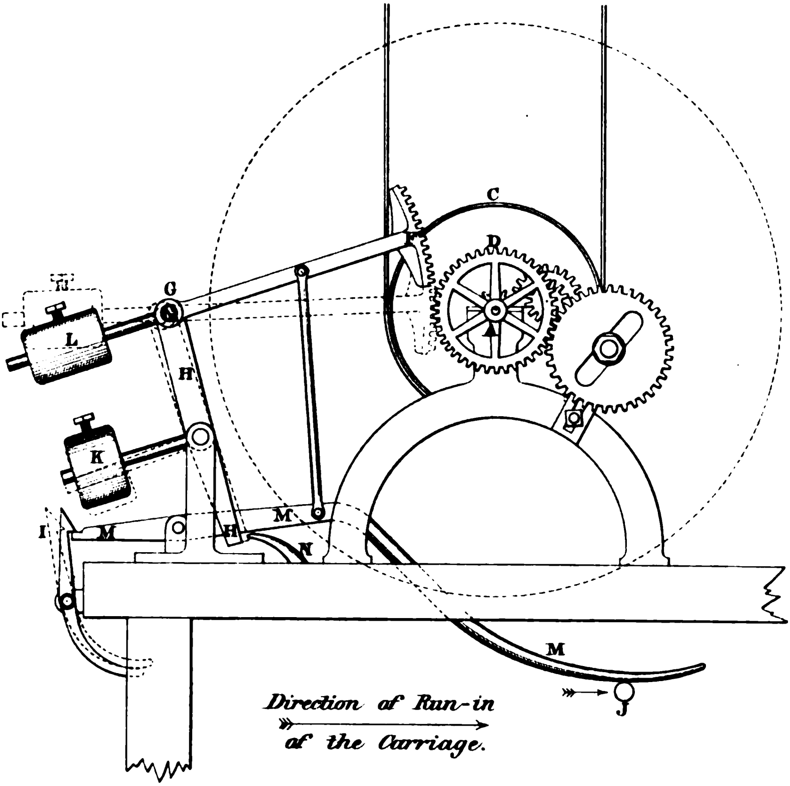
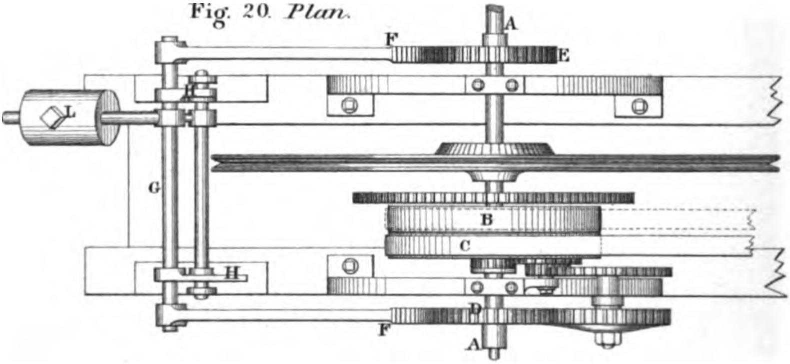


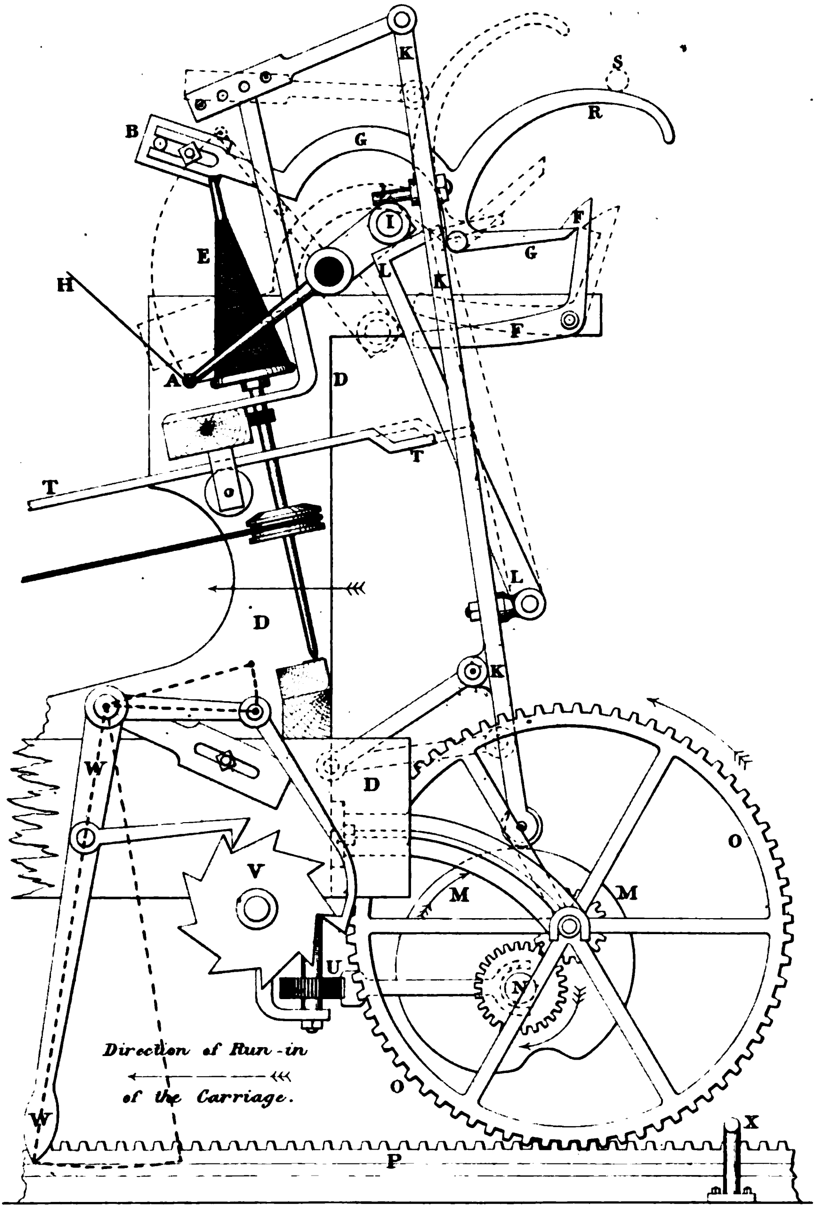
Fig. 20. *Plan.*



(Proceedings Inst. M. E. 1866. Page 199.) *Scale 1/12 th.*

10 5 0 10 20 30 Inches.

Fig. 21. Eaton's Faller Motion. 1818.



(Proceedings Inst. M.E. 1866. Page 199.)

Scale 1/6th

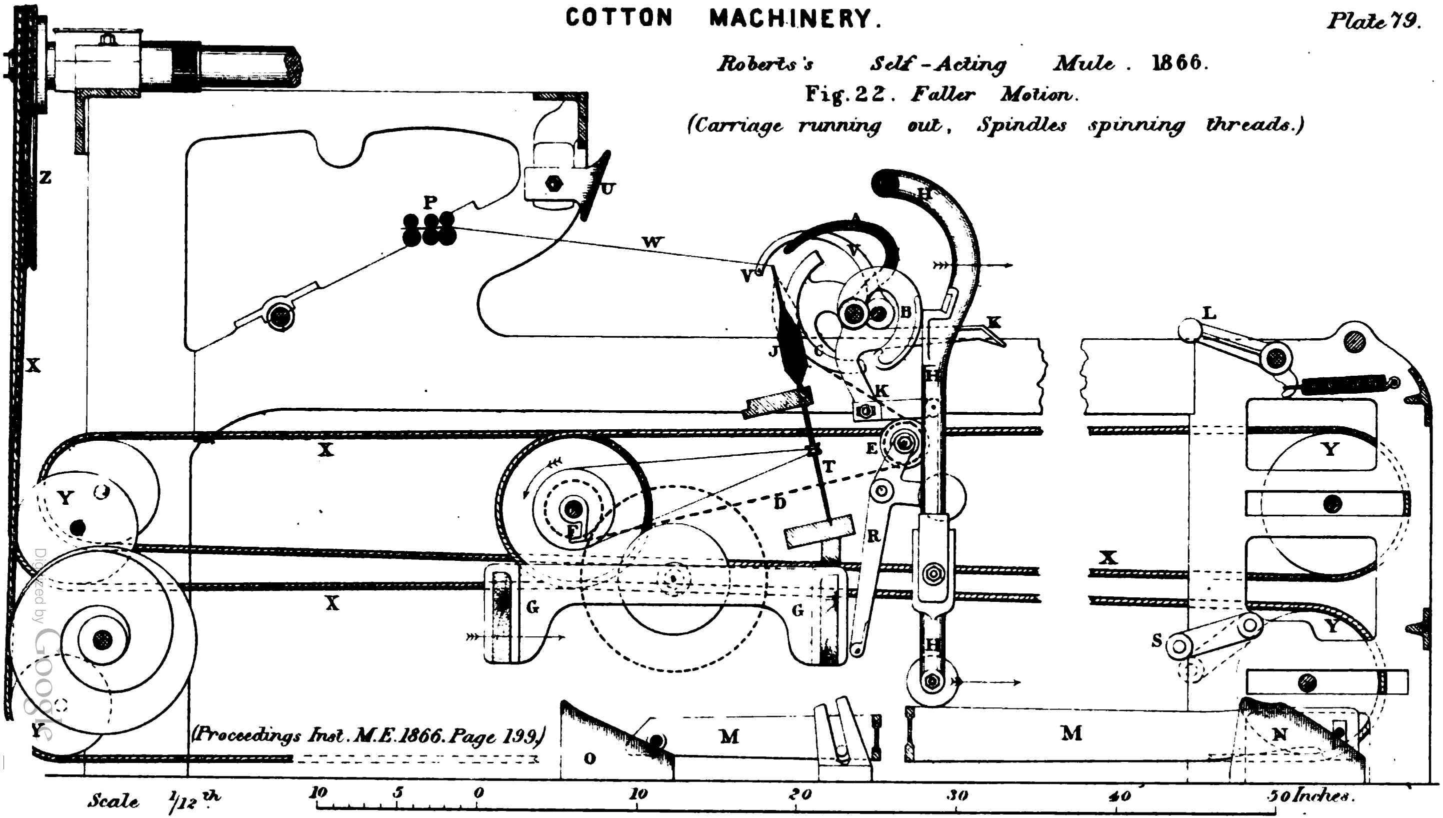
0 5 10 15 20 Inches.

COTTON MACHINERY.

Roberts's Self-Acting Mule. 1866.

Fig. 22. Faller Motion.

(Carriage running out, Spindles spinning threads.)



(Proceedings Inst. M.E. 1866. Page 199.)

Roberts's Self-Acting Mule. 1866. Faller Motion.

Fig. 25. Unlocking of Faller at end of winding.

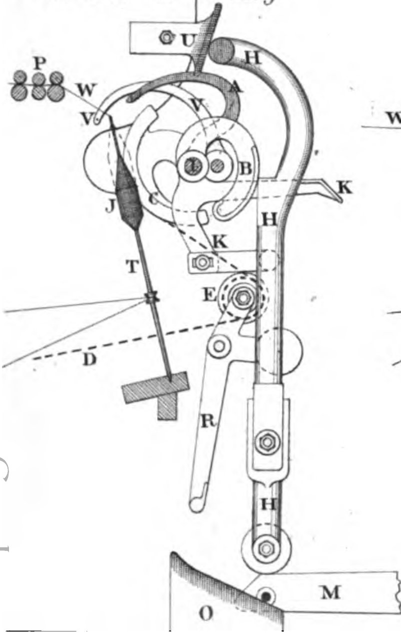


Fig. 24. Locking of Faller previous to winding.

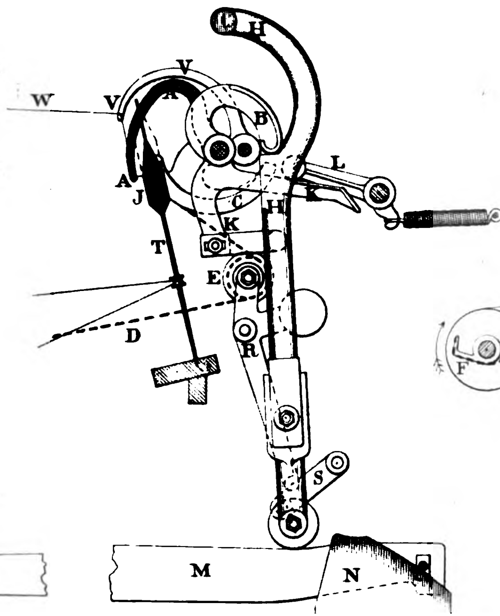


Fig. 23. Putting-down of Faller during Backing-Off.

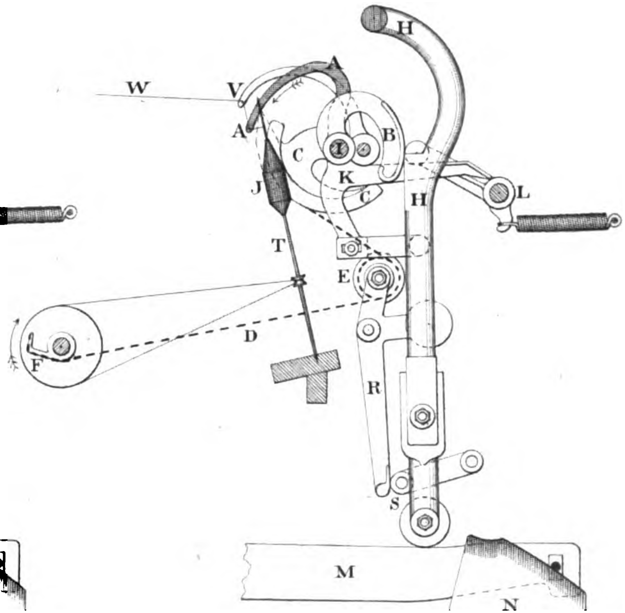
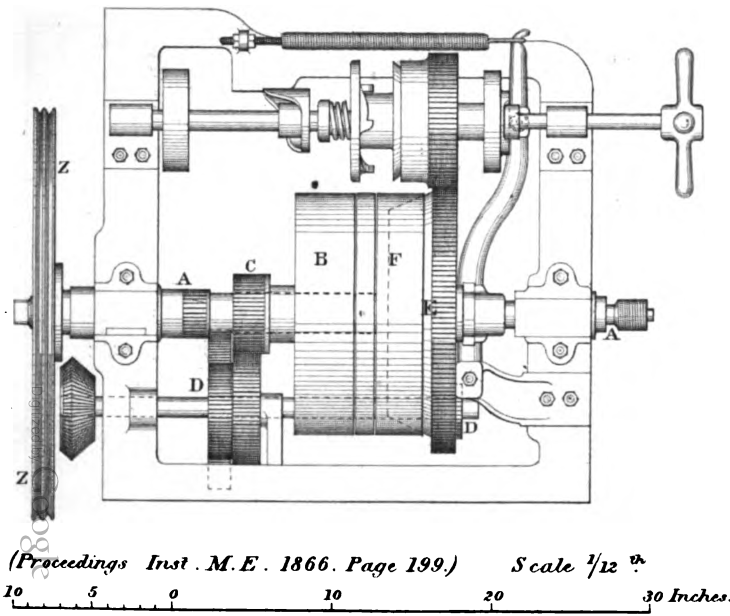


Plate 81.

Roberts's Self-Acting Mule. 1866.

Fig. 28. Plan of Backing-Off Motion.



(Proceedings Inst. M.E. 1866. Page 199.) Scale 1/12 th.

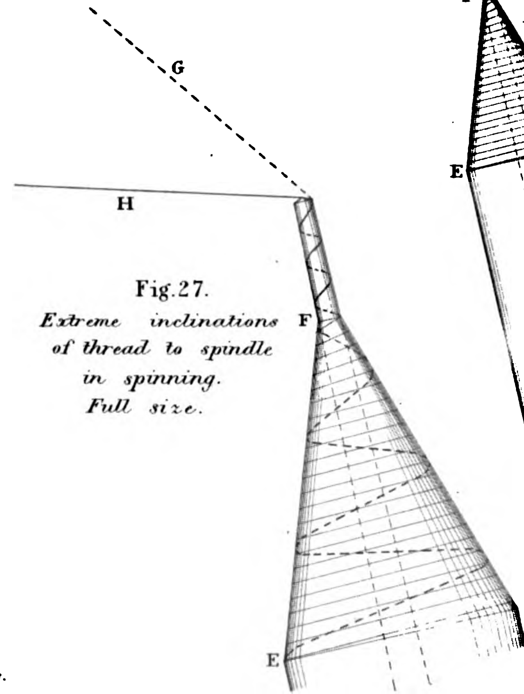
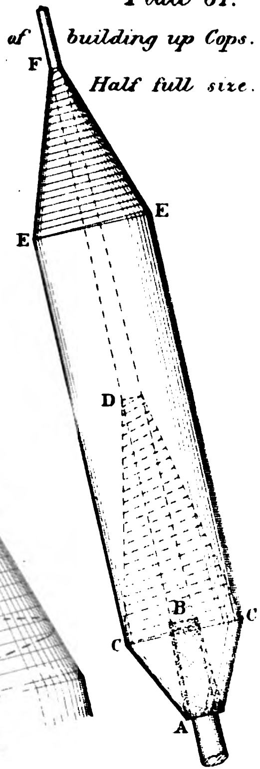


Fig. 27. Extreme inclinations of thread to spindle in spinning. Full size.

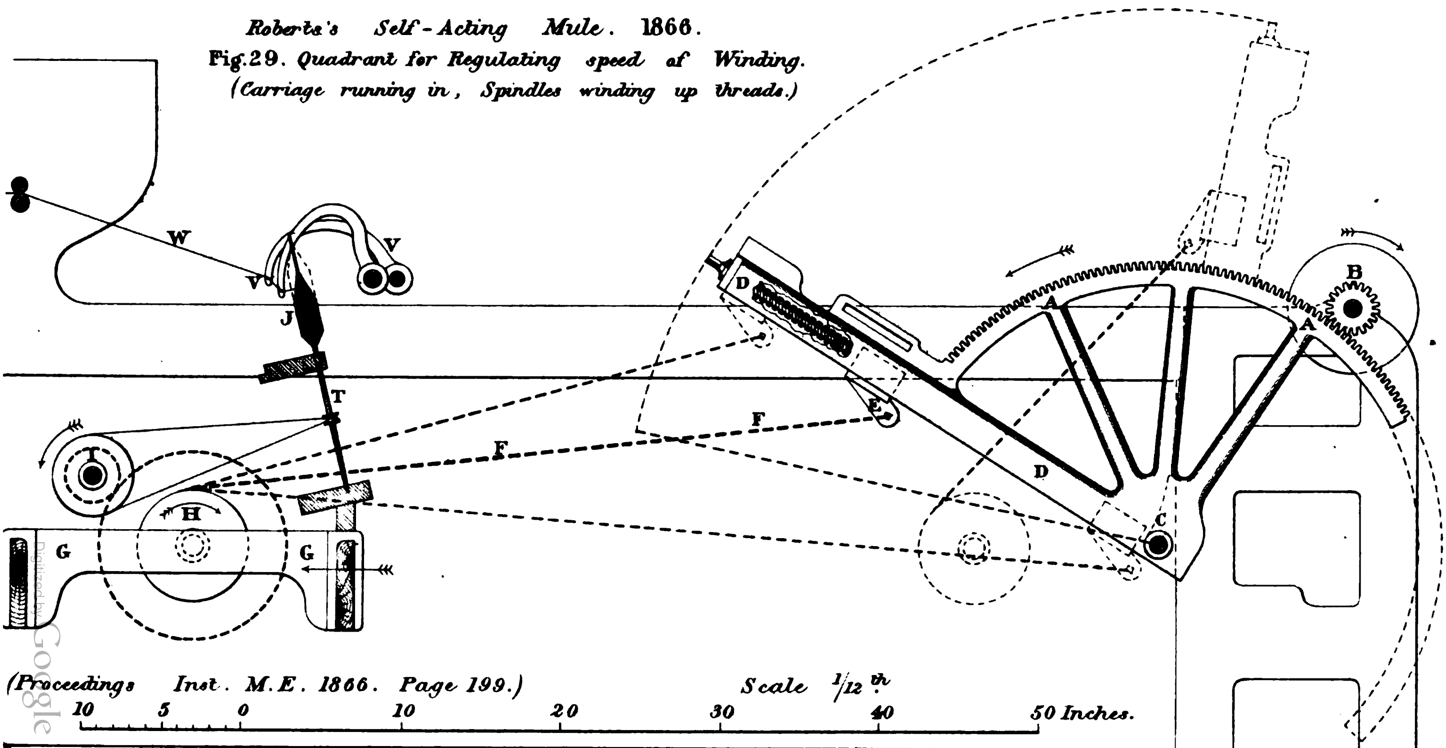
Fig. 26. Mode of building up Cops. Half full size.



Roberts's Self-Acting Mule. 1866.

Fig. 29. Quadrant for Regulating speed of Winding.

(Carriage running in, Spindles winding up threads.)



(Proceedings Inst. M.E. 1866. Page 199.)

MANCHESTER WATER WORKS.

Plate 83.

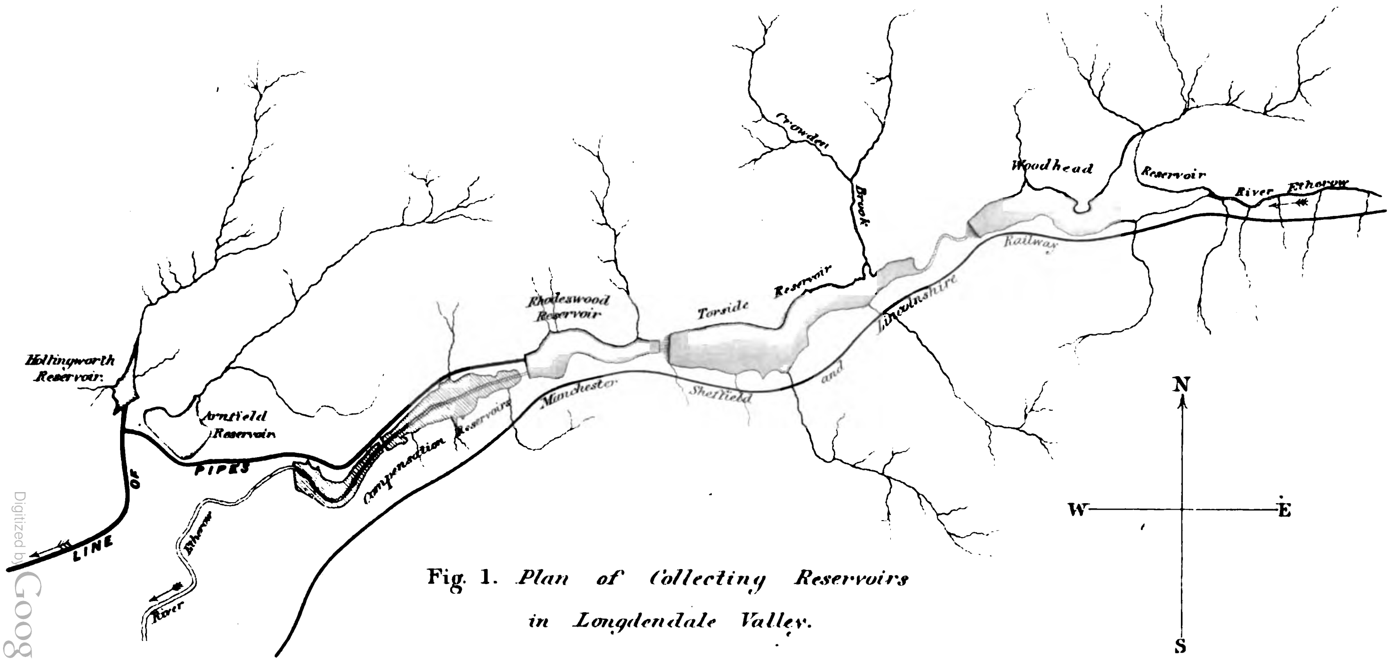


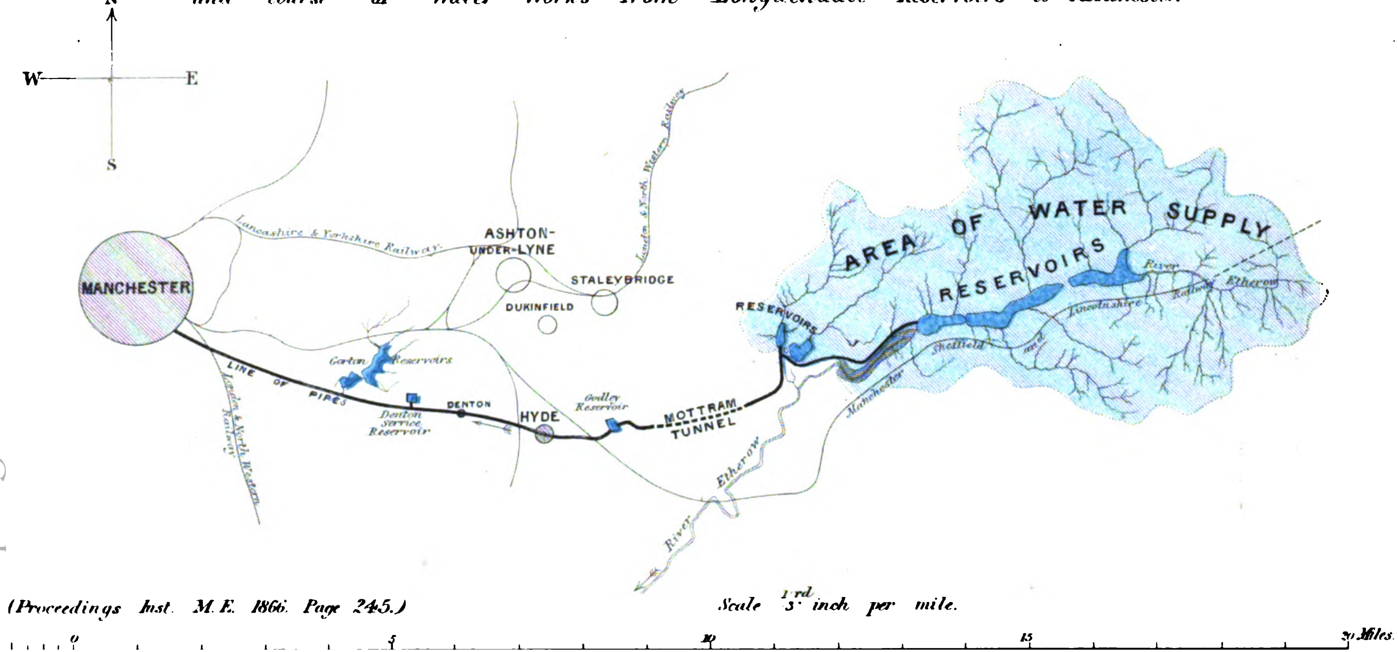
Fig. 1. *Plan of Collecting Reservoirs in Longdendale Valley.*

(Proceedings Inst. M. E. 1866. Page 245.)

Scale 1 inch per mile.

MANCHESTER WATER WORKS.

Fig. 2. *General Plan showing Drainage Area, and course of Water Works from Longdendale Reservoirs to Manchester.*



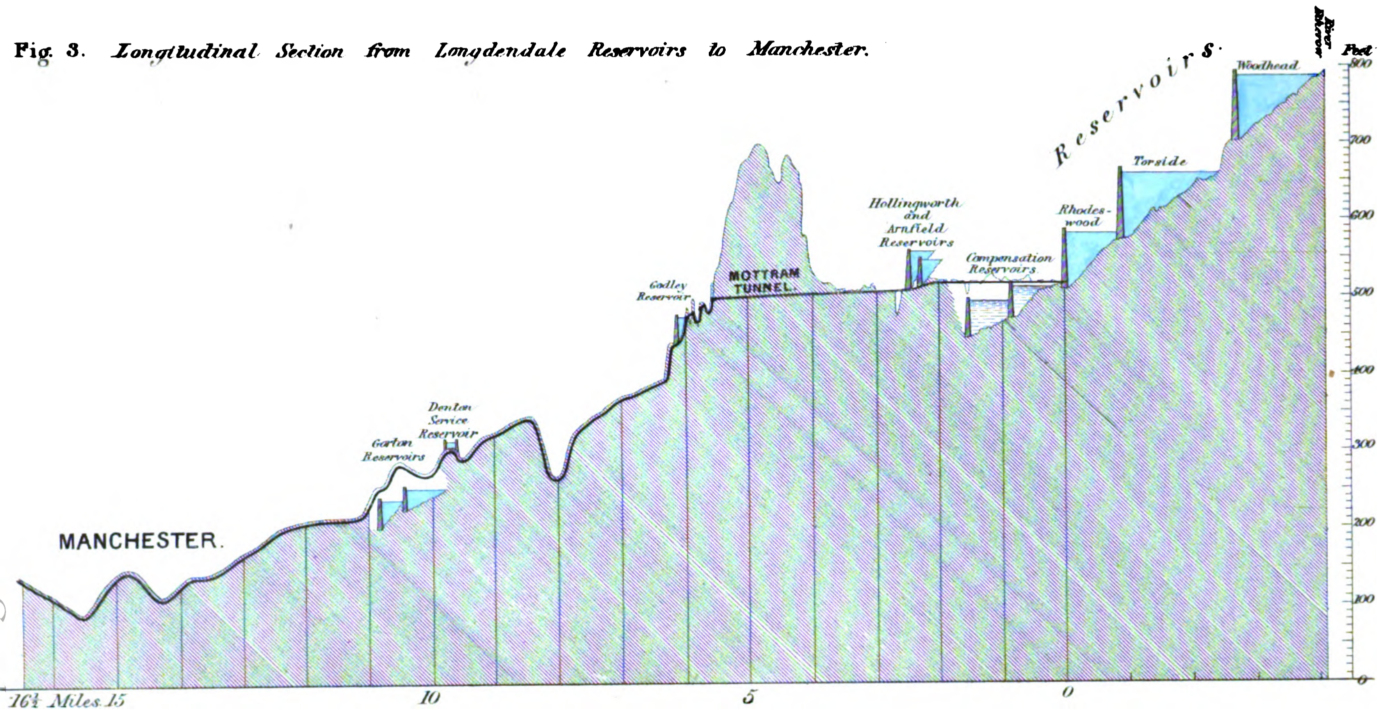
(Proceedings Inst. M.E. 1866. Page 245.)

Scale 1/3rd inch per mile.

MANCHESTER WATER WORKS.

Plate 85.

Fig. 3. *Longitudinal Section from Longdendale Reservoirs to Manchester.*



Horizontal Scale ⅓rd inch per mile.

(Proceedings Inst. M.E. 1866. Page 245.)

MANCHESTER WATER WORKS.

Plate 86.

Fig. 4.

Separation of turbid water in Large streams.

(Pure water coloured blue.)

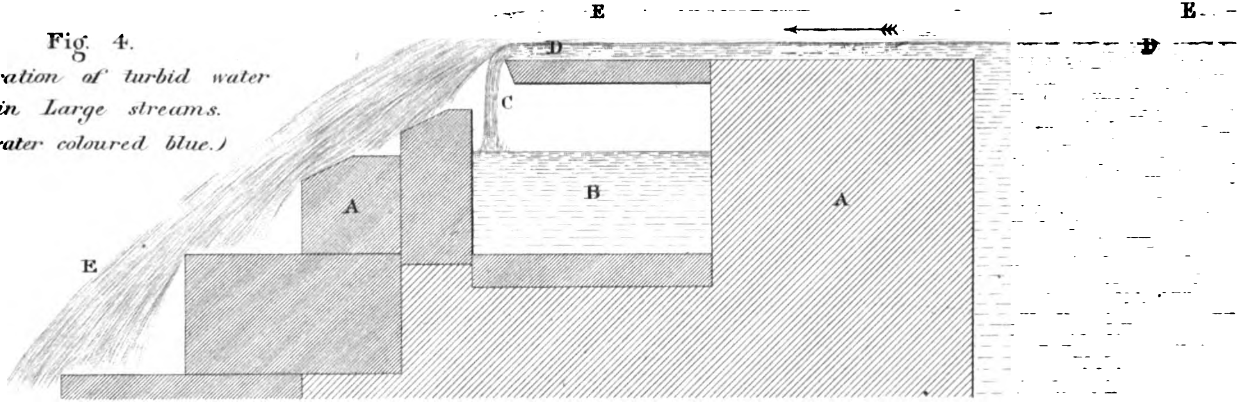


Fig. 5. *Separating arrangement for Small streams.*

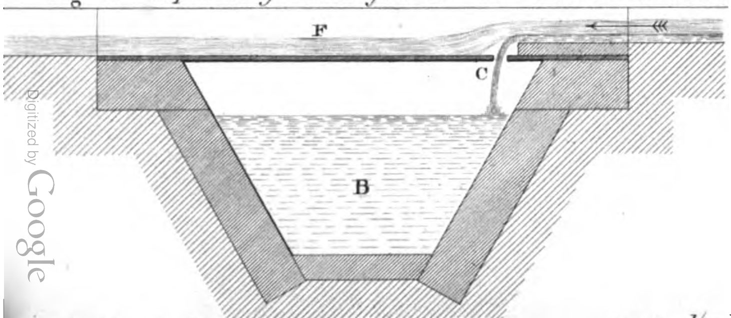
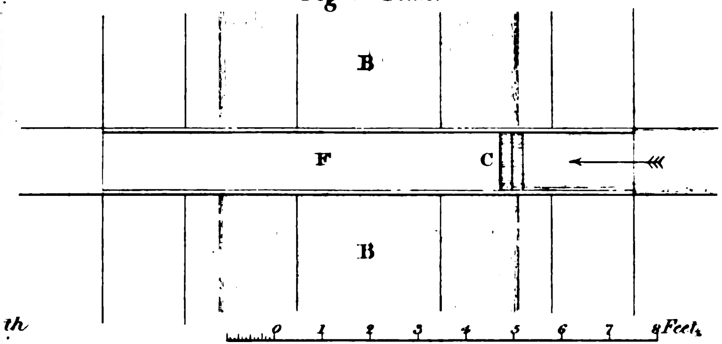


Fig. 6. *Plan.*



(Proceedings Inst. M. E. 1866. Page 245.)

Scale 1/50 th.

MANCHESTER WATER WORKS. *Plate 87.*

48 inch *Sluice Valve at large reservoirs.*

Fig. 7. *Vertical Section.*

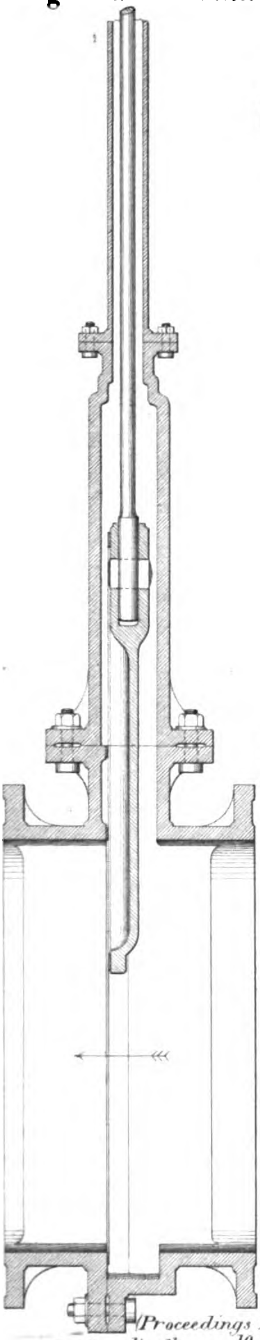


Fig. 8. *Sectional Plan.*

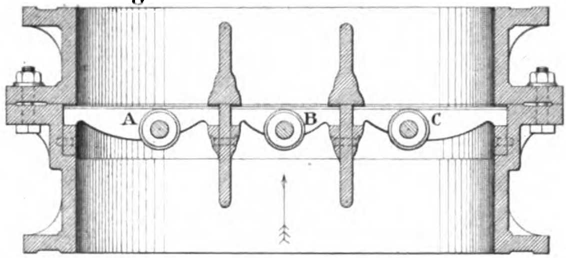
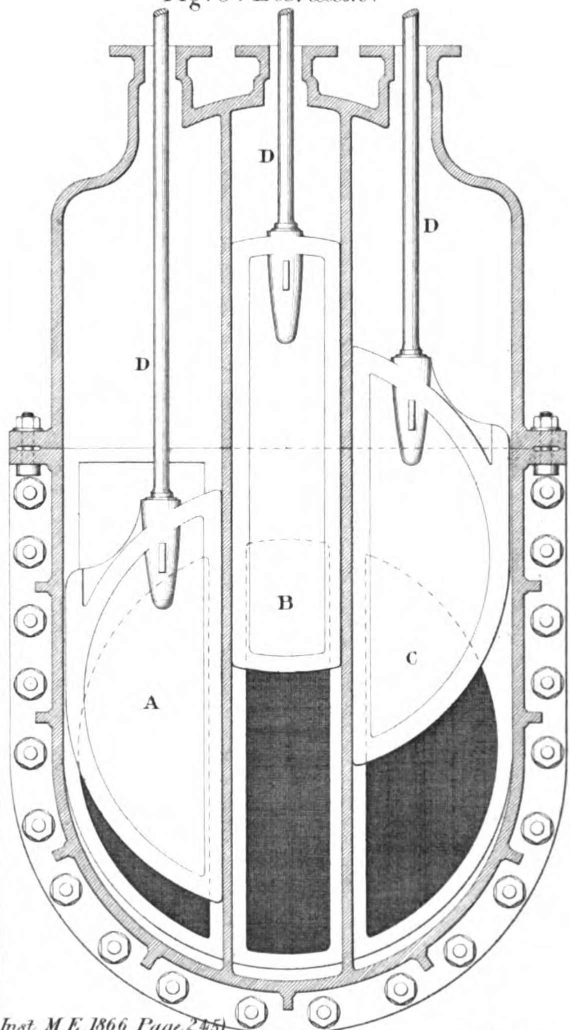


Fig. 9. *Elevation.*



(Proceedings Inst. M.E. 1866. Page 245)

Scale 1/24th. 10 5 0 10 20 30 40 50 *Inches.*

MANCHESTER WATER WORKS.

40 inch Reflux Valve.

Fig. 10. Vertical Section.

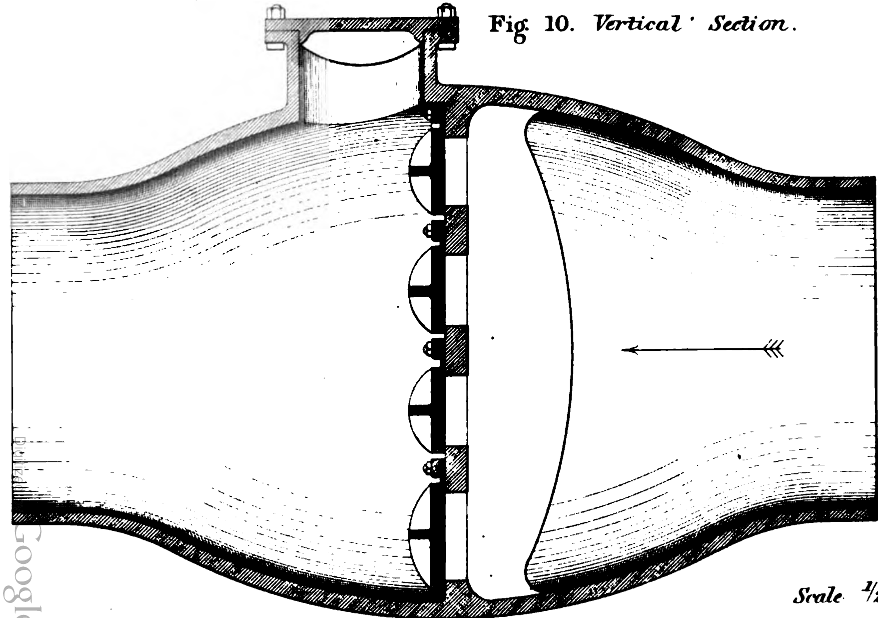
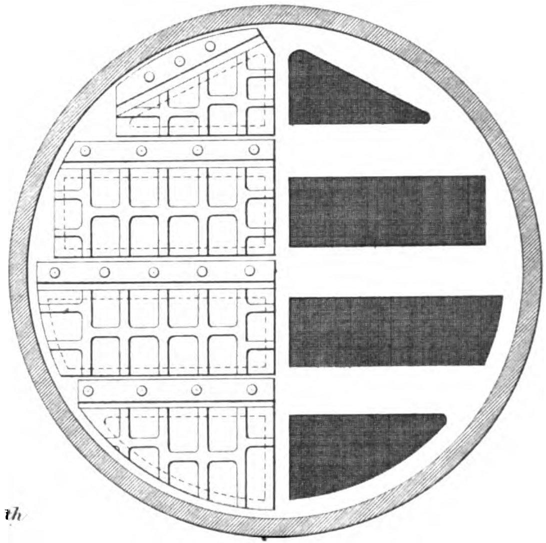


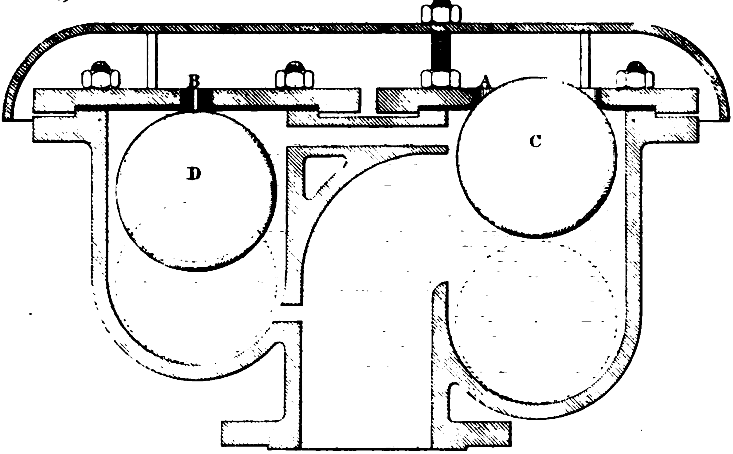
Fig. 11. Elevation.



Scale 1/24th

(Proceedings Inst. M.E. 1866. Page 245.)

Fig. 12. *Vertical Section of Self-Acting Air Valve. Scale 1/10th.*



Hydrant or Fire-Cock.

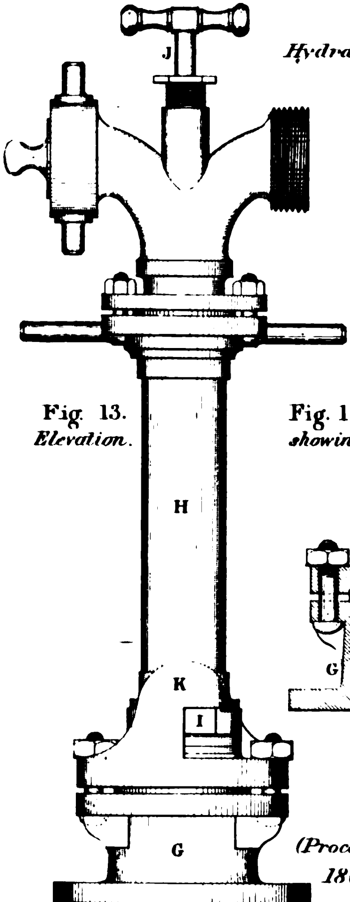
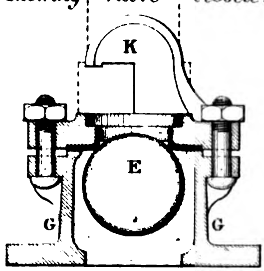


Fig. 13. *Elevation.*

Fig. 15. *Vertical Section showing Valve closed.*



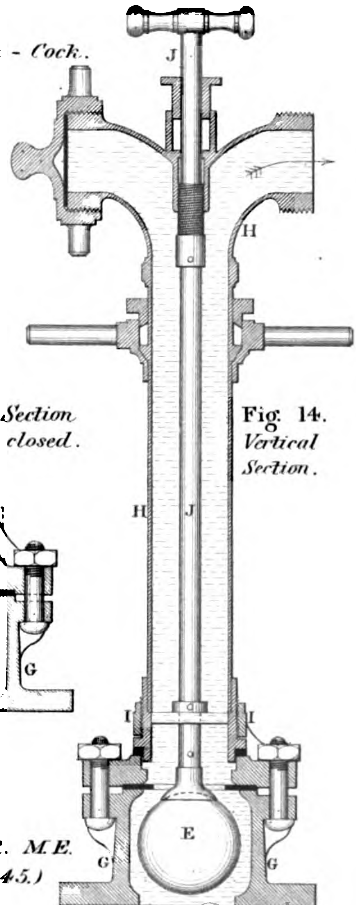


Fig. 14. *Vertical Section.*

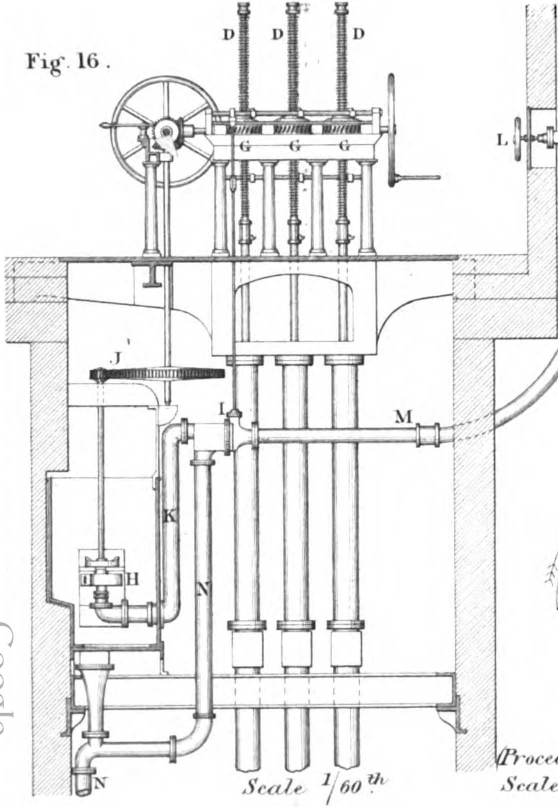
(Proceedings Inst. M.E. 1866. Page 245.)

Scale 1/6th 0 5 10 15 *Inches.*

MANCHESTER WATER WORKS.

Turbine for opening Sluice Valves at reservoirs.

Fig. 16.



Scale 1/60th.

Fig. 18.

Plan of Turbine.

Scale 1/10th.

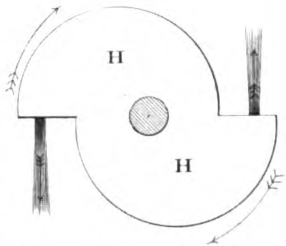
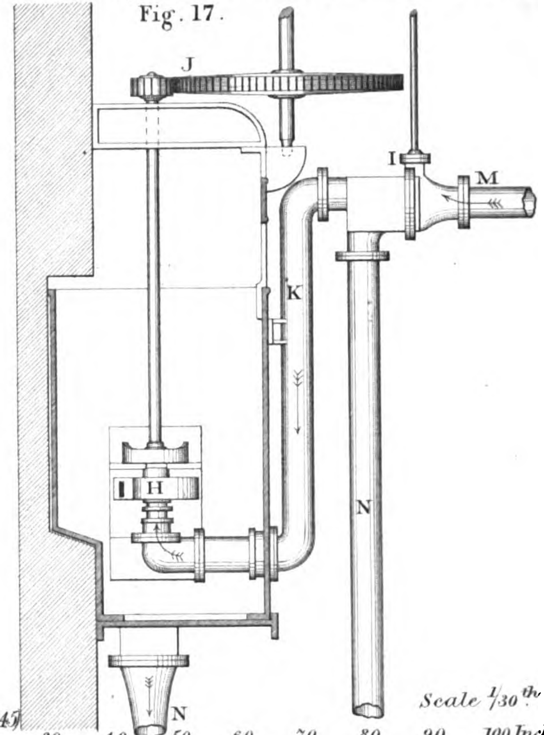
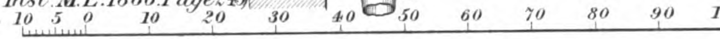


Fig. 17.



Scale 1/30th.



Scale 1/30th.

(Proceedings Inst. M.E. 1866. Page 245)

MANCHESTER WATER WORKS.

Gauge Sluice in watercourses.
Scale 1/32nd.

Fig. 19.
Elevation.

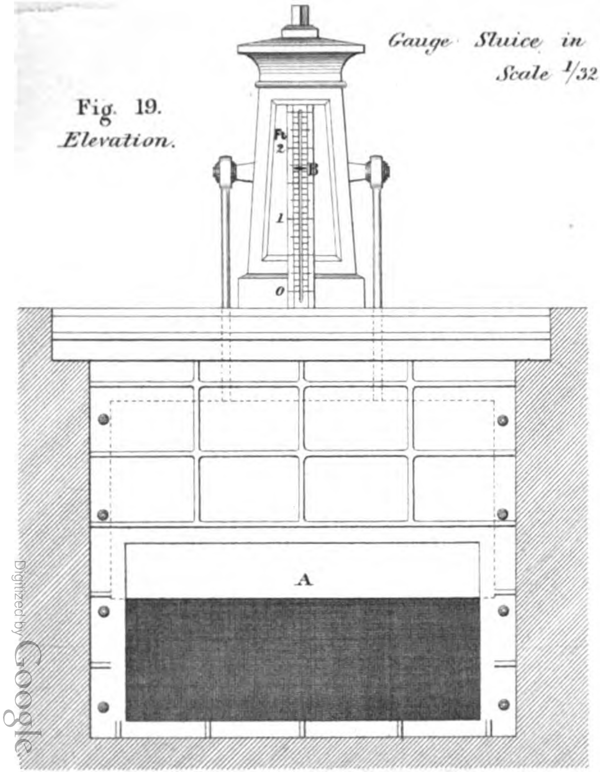
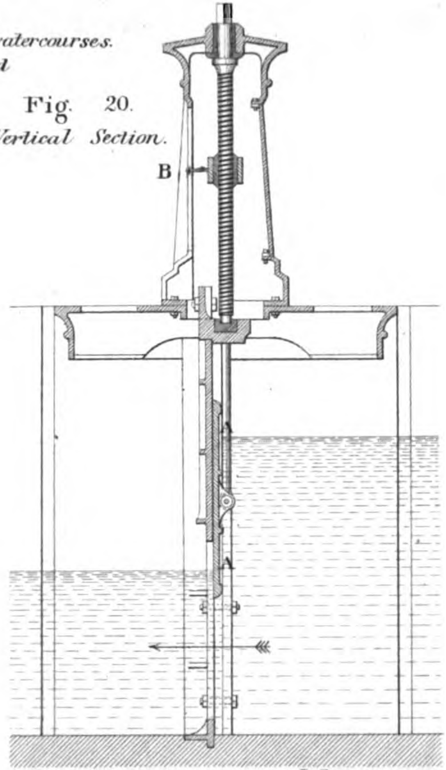


Fig. 20.
Vertical Section.



Scale 1/32nd. 10 5 0 10 20 30 40 50 60 70 80 90 100 Inches.

Fig. 21. Sectional Plan of Headstock. Scale 1/16th.

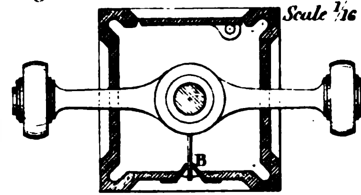


Fig. 22. Enlarged Plan of Index. Scale 1/4th.

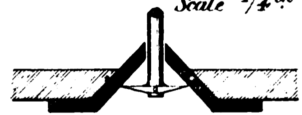
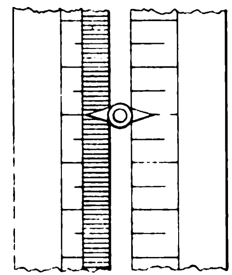


Fig. 23. Elevation of Index.



MANCHESTER WATER WORKS.

Plate 92.

Transverse Vertical Sections of Gauge Plate at Godley Reservoir. Rectangular Openings, 6 ft. wide by 6 ins. high.

Fig. 24. *Coefficient* 5·6

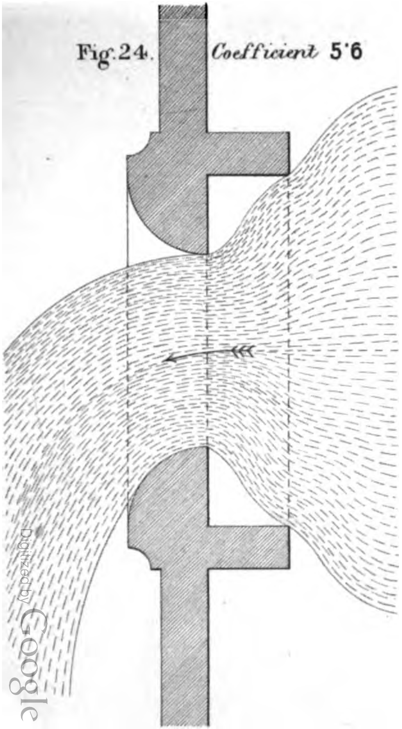


Fig. 25. *Coefficient* 7·0

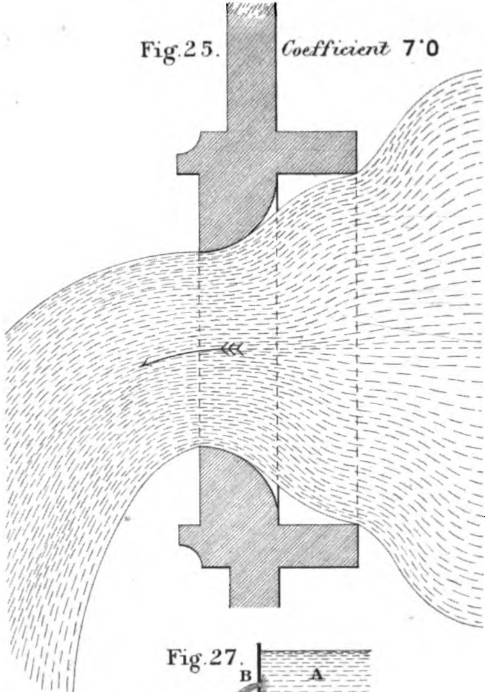


Fig. 26. *Coefficient* 7·6

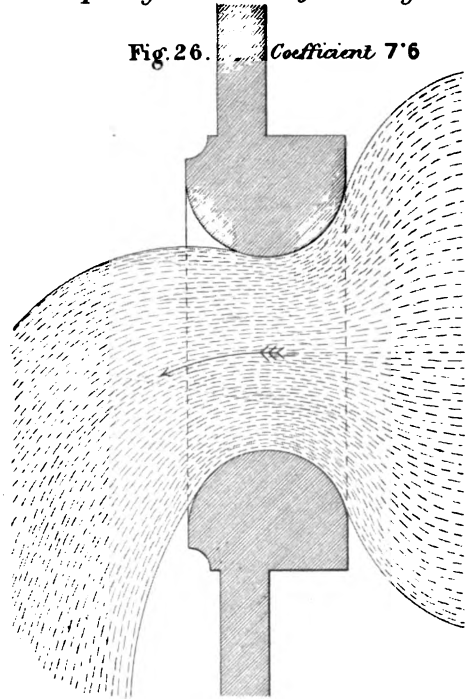
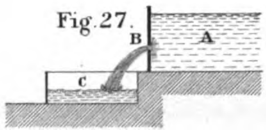


Fig. 27.



Scale 1/6th

0 1 2 3 4 5 6 7 8 9 10 Inches.

(Proceedings Inst. M.E. 1866. Page 245.)

Gauging of Compensation Water for mills.

Fig. 28. *Plan.*

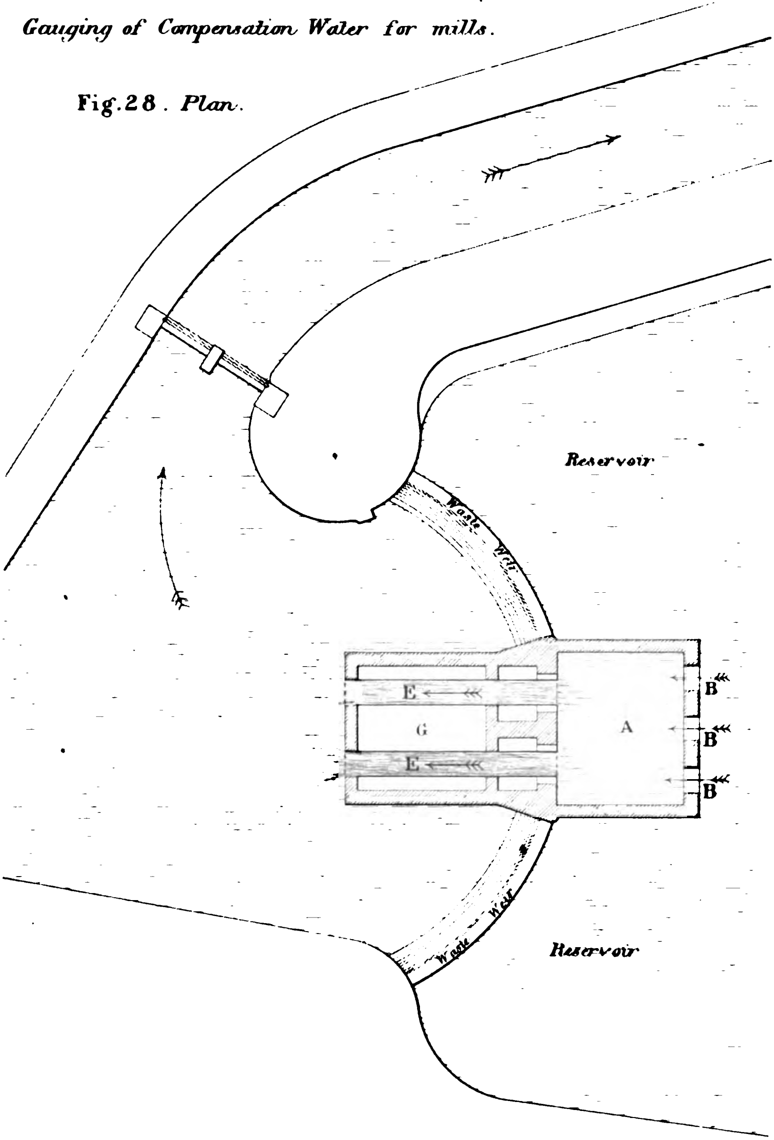
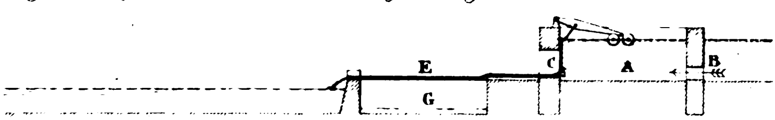


Fig. 29. *Longitudinal Section through Gauge Basin and Test Basin.*



(Proceedings Inst. M. E. 1866. Page 245.) *Scale 1/500th.*

10 5 0 50 100 150 Feet.

Fig. 30. *Self-adjusting Gauge for uniform discharge under varying head.*

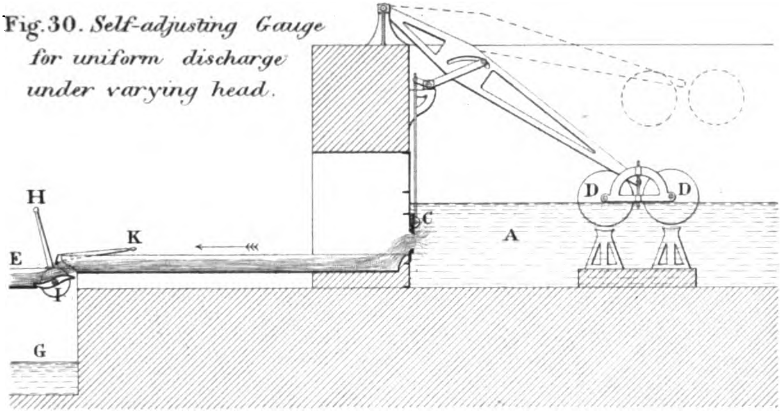


Fig. 31. *Elevation of Gauge Plate.* *Scale 1/24th*

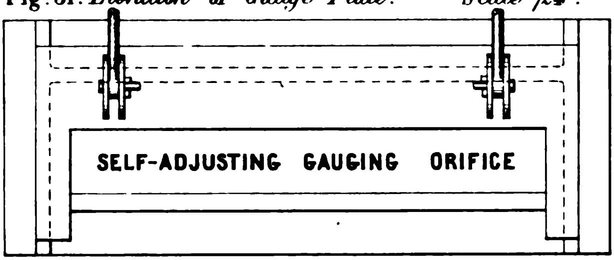
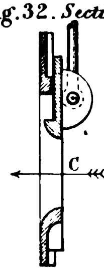


Fig. 32. *Section.*



Reversing Tumbler in Discharge Trough. *Scale 1/24th.*

Fig. 33. *Ordinary open position.*

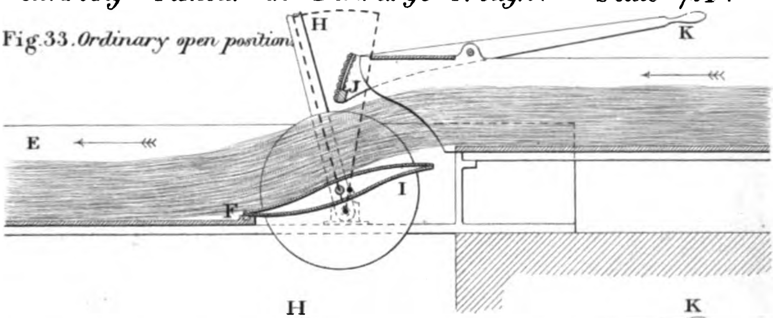
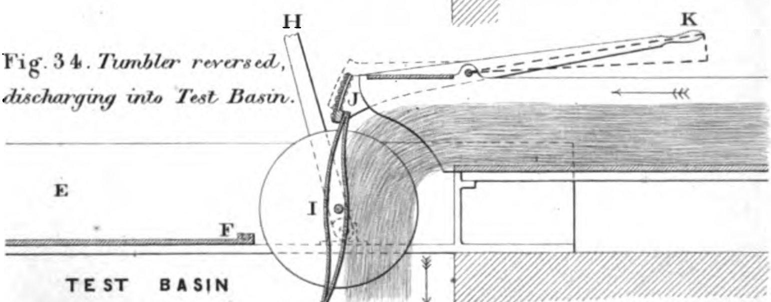


Fig. 34. *Tumbler reversed, discharging into Test Basin.*



(Proceedings Inst. M.E. 1866. Page 245) *Scale 1/24th.*

Ins. 12 6 0 1 2 3 4 5 6 Feet.

SELF-ADJUSTING INJECTOR. *Plate 95.*

Fig. 1. Original Giffard's Injector.
Scale 1/10th

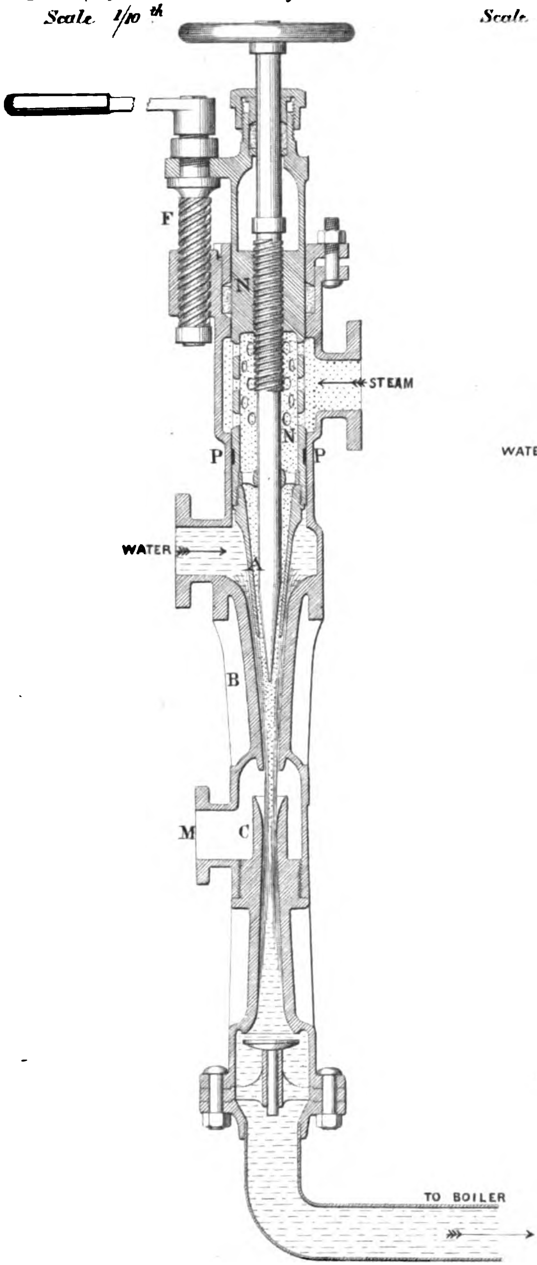


Fig. 2. Rack and Pinion Injector.
Scale 1/10th

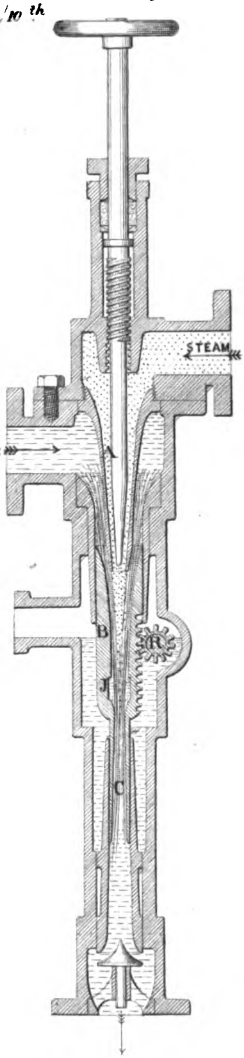
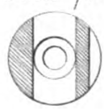


Fig. 3. Transverse Section at J.
Scale 1/5th



(Proceedings Inst. M.E. 1866. Page 266.)

Scale 1/10th 0 5 10 15 20 25 30 *Inches*

SELF-ADJUSTING INJECTOR. *Plate 96.*

Sellers' Self-Adjusting Injector.

Fig 4. *Vertical Section.*

Scale 1/10th

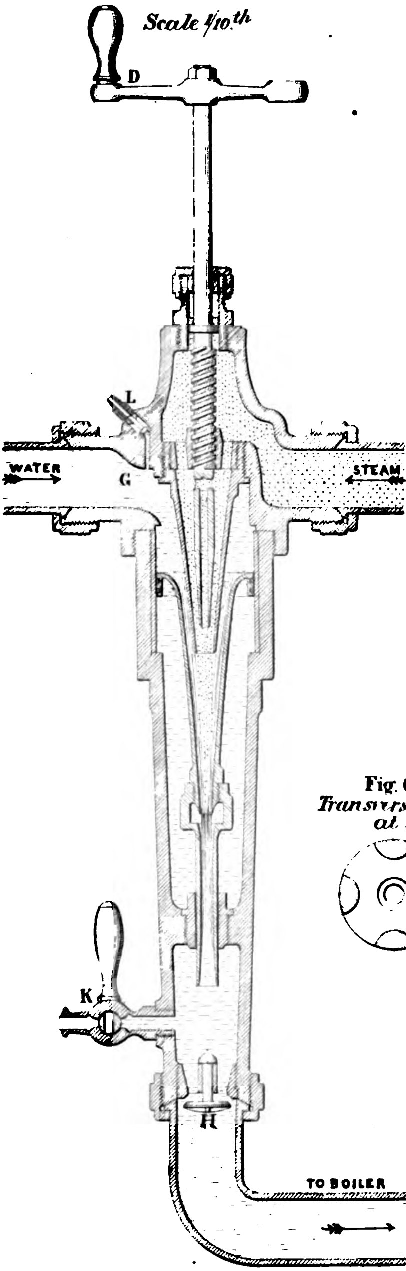


Fig 5. *Vertical Section, enlarged.*

Scale 1/5th

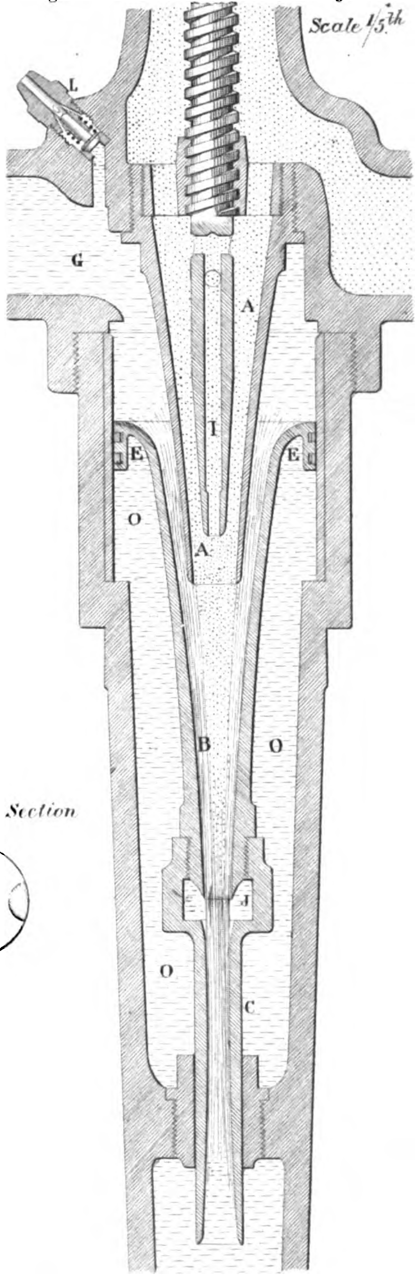


Fig. 6.
Transverse Section at J.

(Proceedings Inst. M.E. 1866. Page 266)

Scale 1/10th 0 5 10 15 20 25 30 Inches

Self-Starting and Self-Adjusting Injector.

Fig. 7. Scale 1/10th

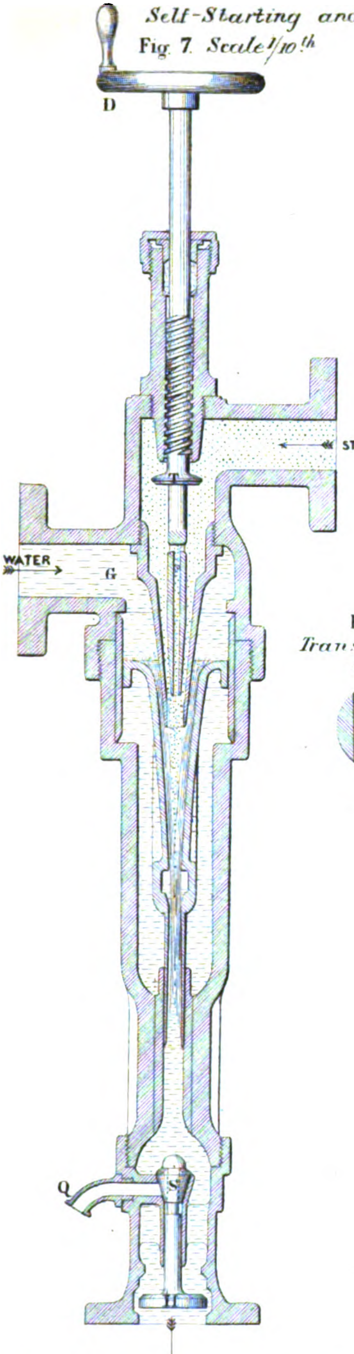


Fig. 8. Scale 1/5th

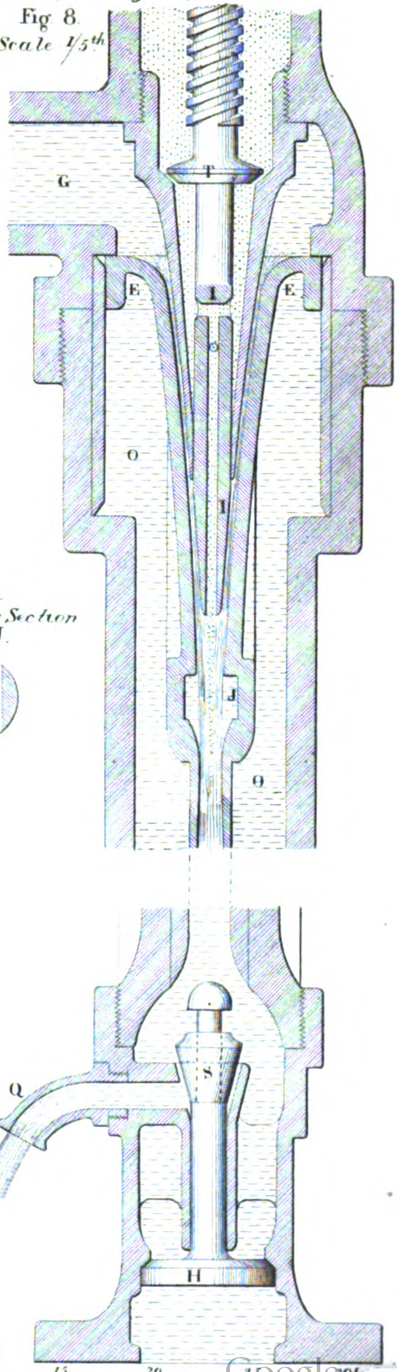


Fig. 9. *Transverse Section at J.*

(*Proceedings Inst. M.E. 1866 Page 266.*)

Scale 1/10th 0 5 10 15 20 25 30

SELF-ADJUSTING INJECTOR. *Plate 98.*

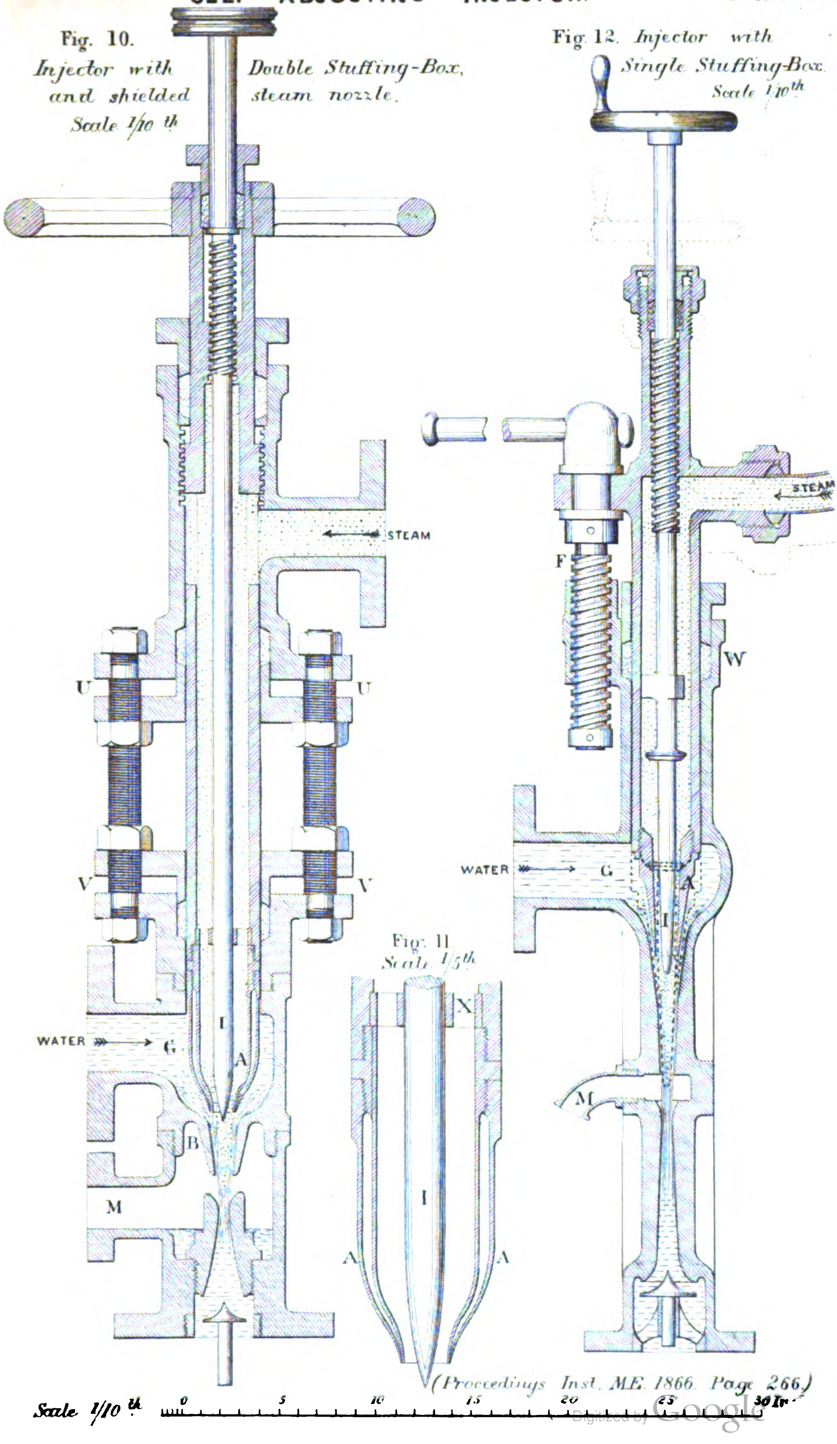


Fig. 10. Injector with Double Stuffing-Box, and shielded steam nozzle. Scale 1/10th

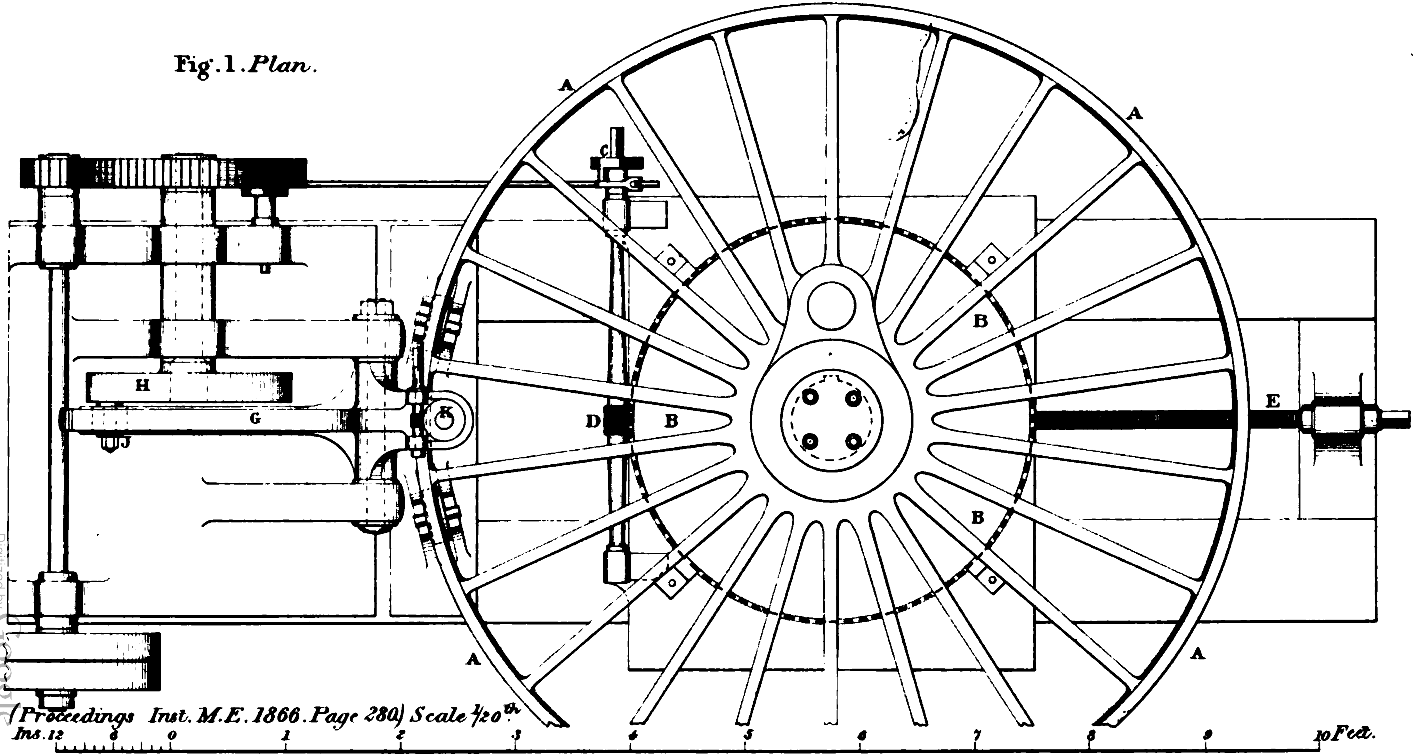
Fig. 11. Scale 1/5th

Fig. 12. Injector with Single Stuffing-Box. Scale 1/10th

(Proceedings Inst. M.E. 1866. Page 266.)

CURVILINEAR SHAPING MACHINE.

Fig. 1. *Plan.*



(Proceedings Inst. M.E. 1866. Page 280) Scale 1/20th.

CURVILINEAR SHAPING MACHINE.

Fig. 2. Longitudinal Section.

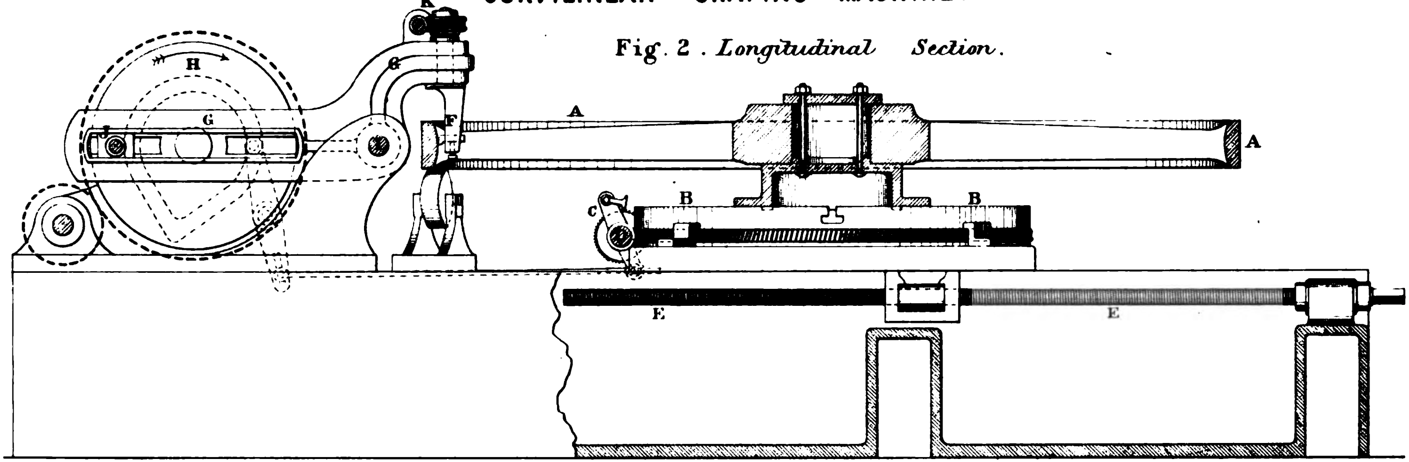


Fig. 3.

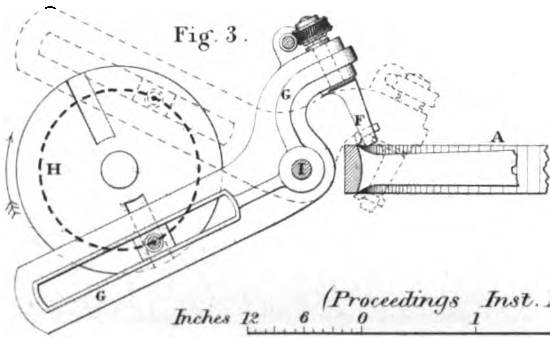
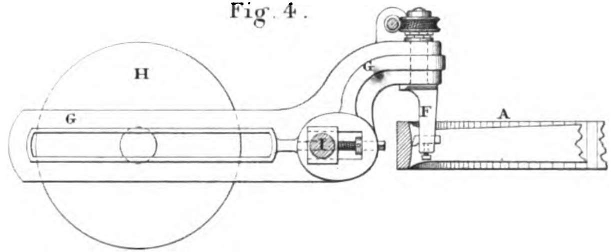


Fig. 4.



(Proceedings Inst. M.E. 1866. Page 280.)

Scale 1/20th.

Inches 12 6 0 1 2 3 4 5 6 7 8 Feet.

CURVILINEAR SHAPING MACHINE.

Fig. 5.

Back Elevation.

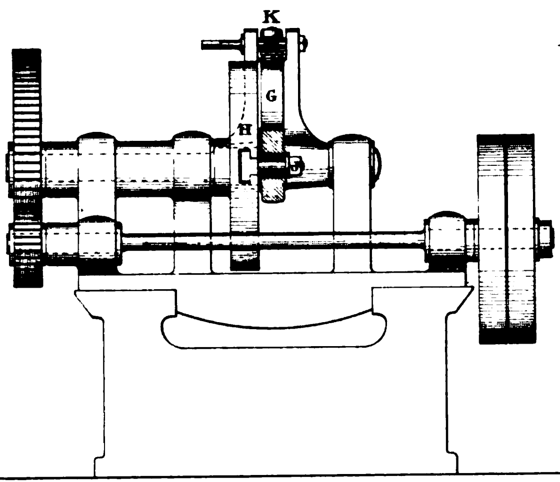
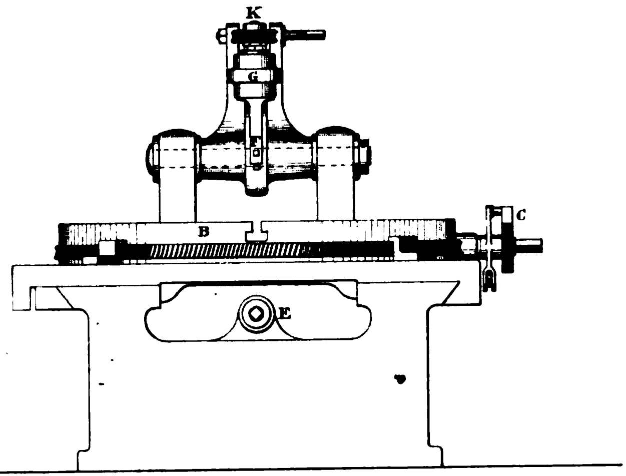


Fig. 6.

Front Elevation.



(Proceedings Inst. M.E. 1866. Page 280.) *Scale 1/20th* *Inches* 12 6 0 1 2 3 4 5 *Feet.*

SELF-ADJUSTING INJECTOR. *Plate 96.*

Sellers' Self-Adjusting Injector.

Fig 4. *Vertical Section.*

Scale 1/10th

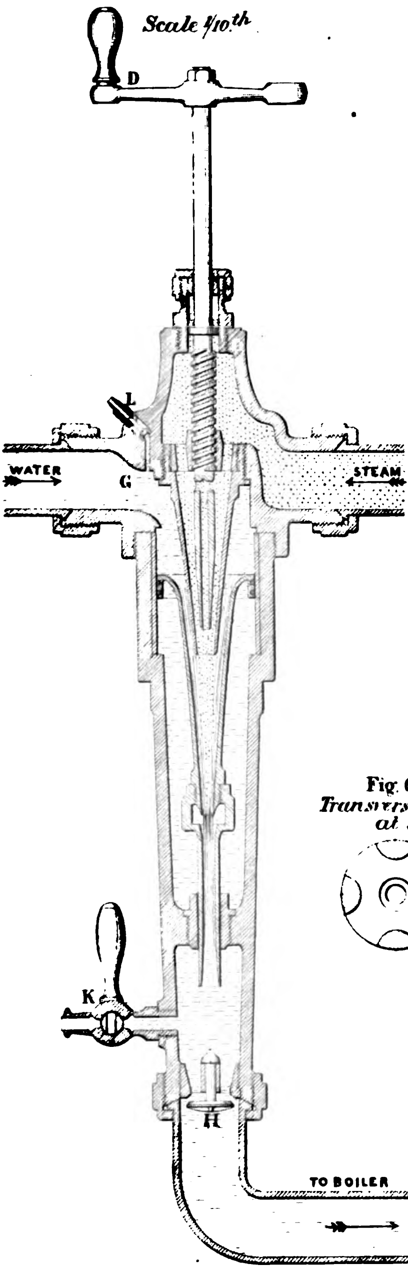


Fig 5 *Vertical Section, enlarged.*

Scale 1/5th

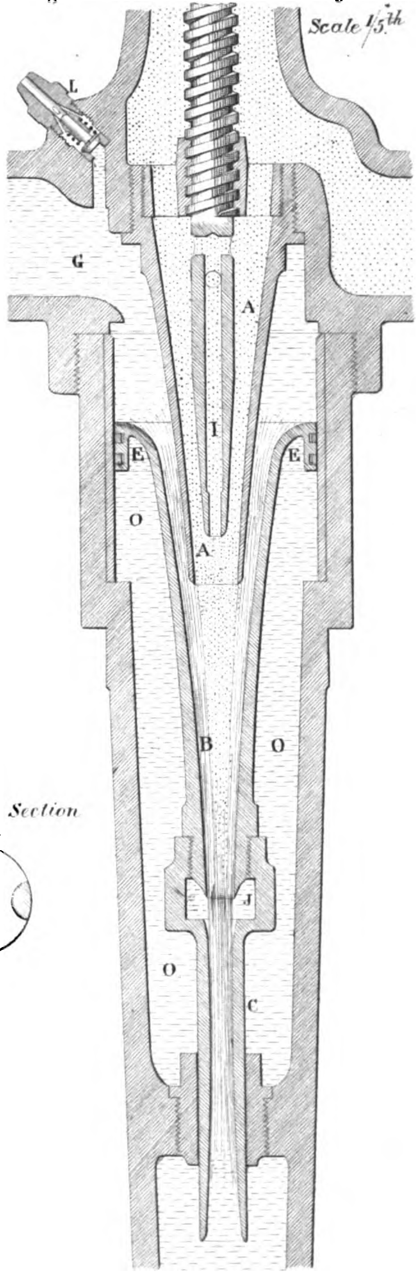


Fig. 6.
Transverse Section at J.

(Proceedings Inst. M.E. 1866 Page 266)

Scale 1/10th 0 5 10 15 20 25 30 in

SELF-ADJUSTING INJECTOR. *Plate 97.*

Self-Starting and Self-Adjusting Injector.

Fig. 7. Scale 1/10th

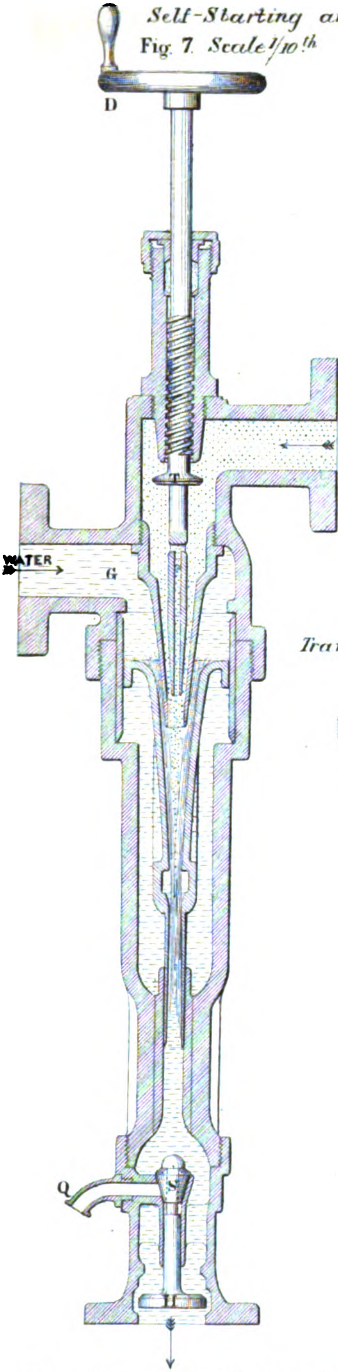


Fig. 8. Scale 1/5th

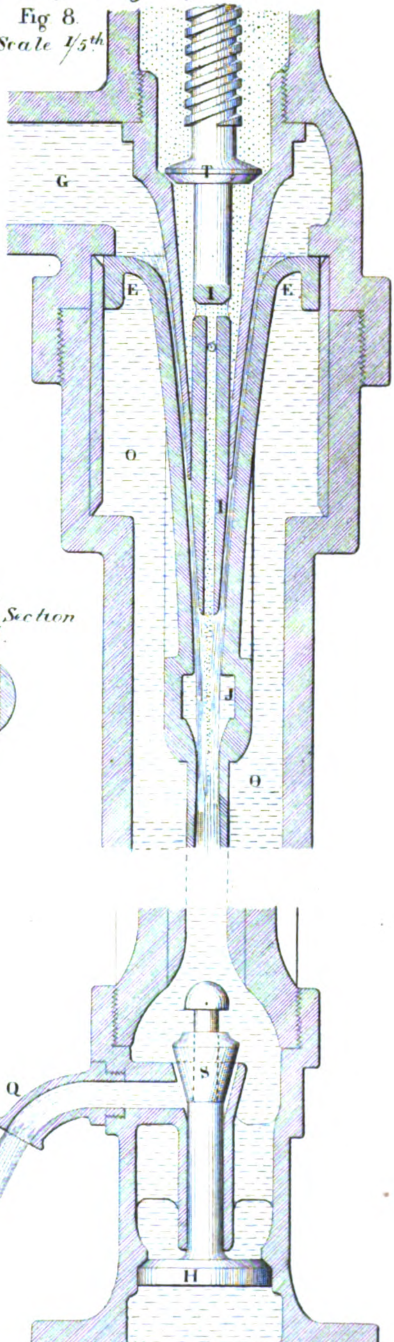


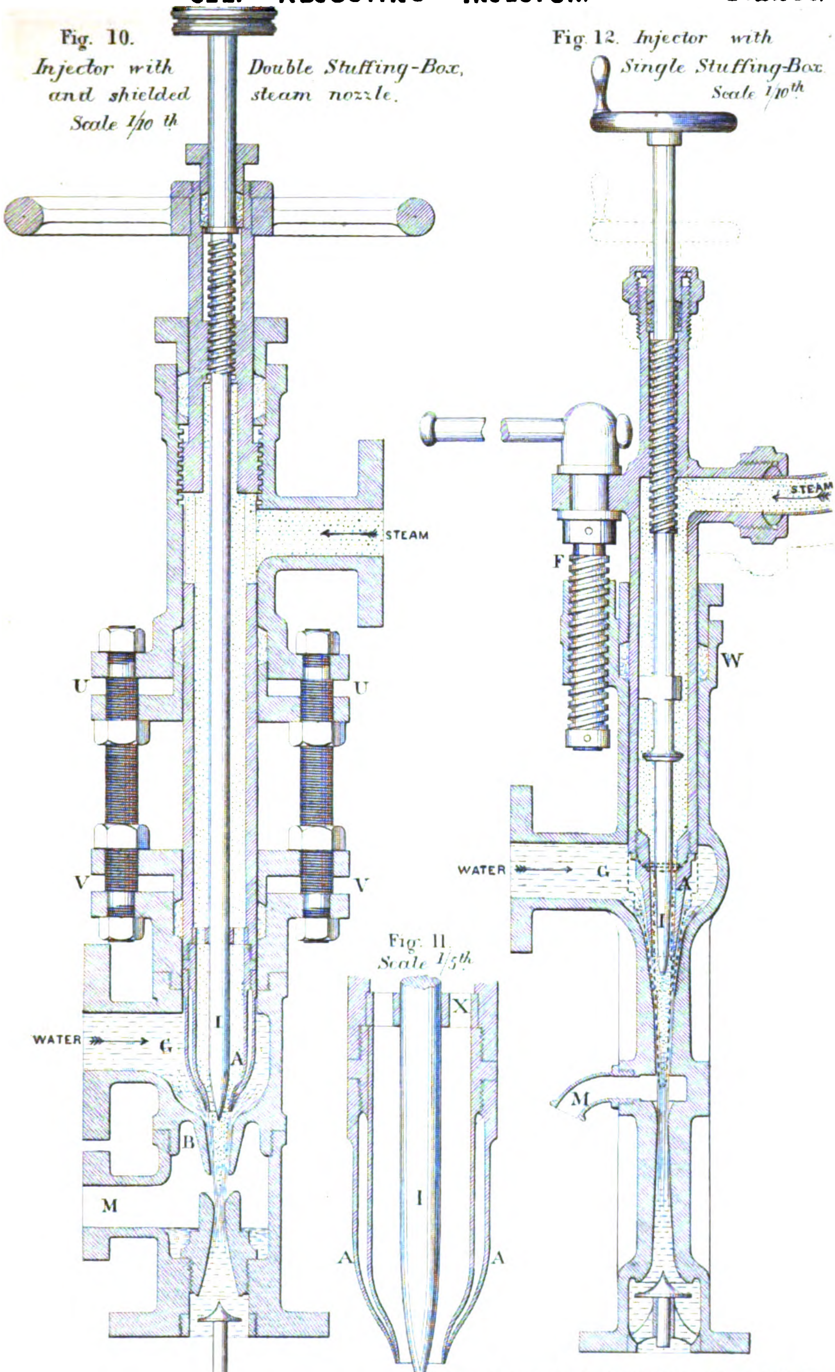
Fig. 9. Transverse Section at J.

(Proceedings Inst. M.E. 1866. Page 266.)

Scale 1/10th 0 5 10 15 20 25 30 Inches

Fig. 10. *Injector with Double Stuffing-Box, and shielded steam nozzle. Scale 1/10 th*

Fig. 12. *Injector with Single Stuffing-Box. Scale 1/10 th*

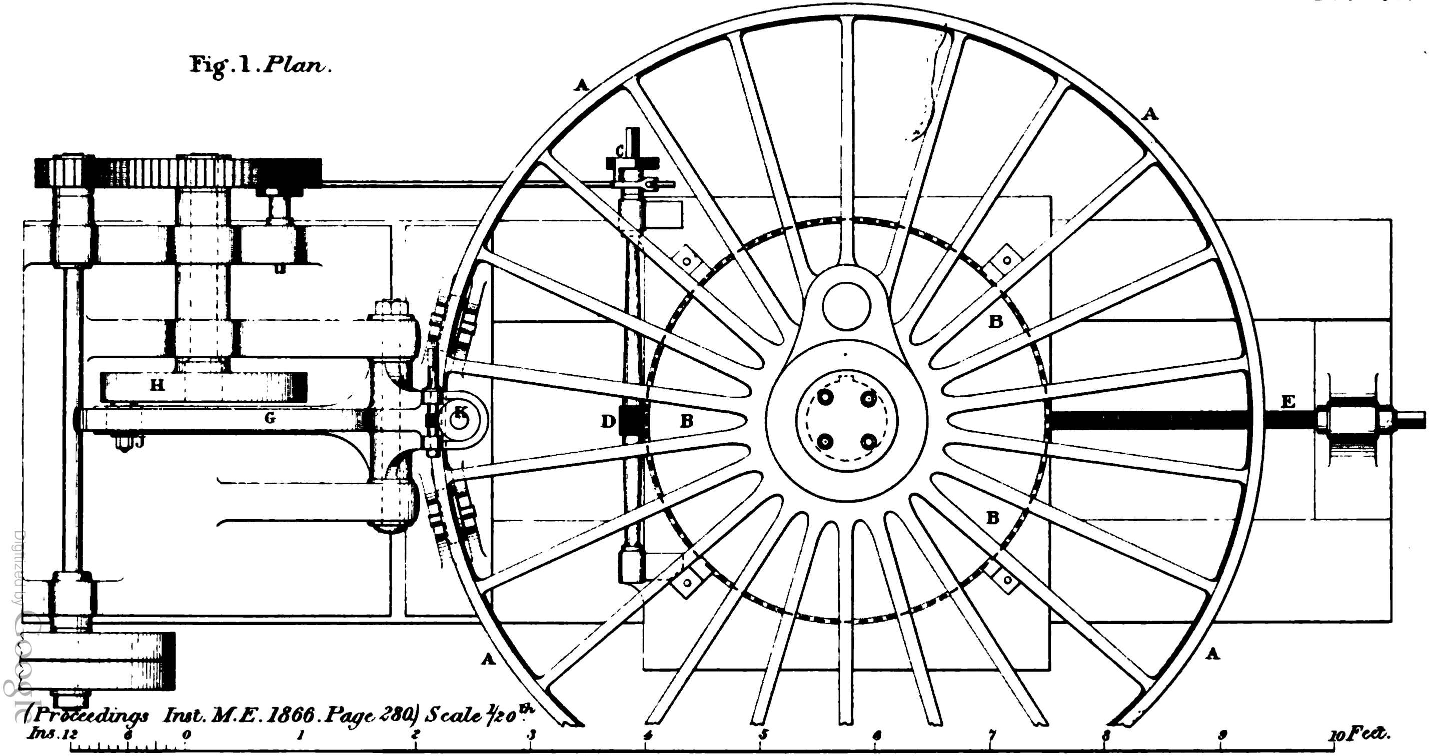


(Proceedings Inst. M.E. 1866. Page 266.)

Scale 1/10 th. 0 5 10 15 20 25 30 Inches.

CURVILINEAR SHAPING MACHINE.

Fig. 1. Plan.



 Scale 1/20th

CURVILINEAR SHAPING MACHINE.

Fig. 2. Longitudinal Section.

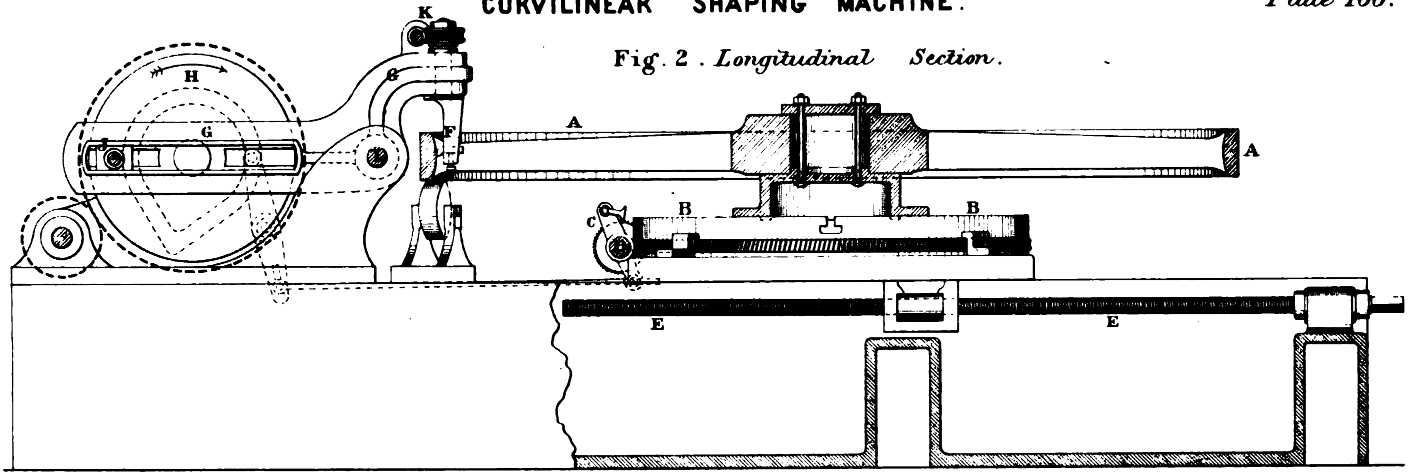


Fig. 3.

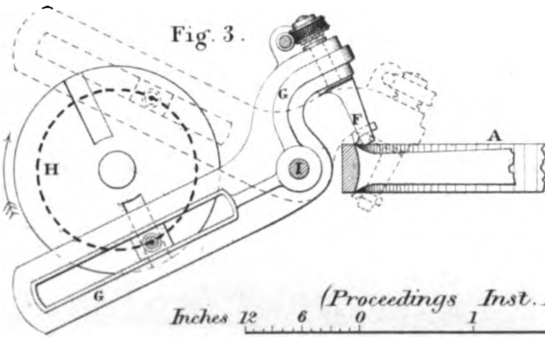
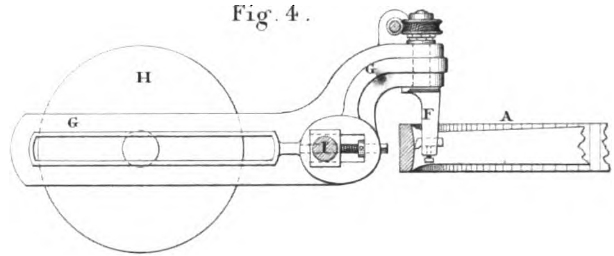


Fig. 4.



(Proceedings Inst. M.E. 1866. Page 280.)

Scale 1/20th.

Inches 12 6 0 1 2 3 4 5 6 7 8 Feet.

CURVILINEAR SHAPING MACHINE.

Fig. 5.

Back Elevation.

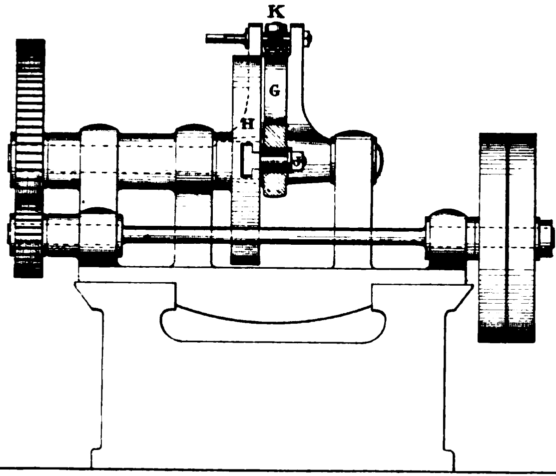
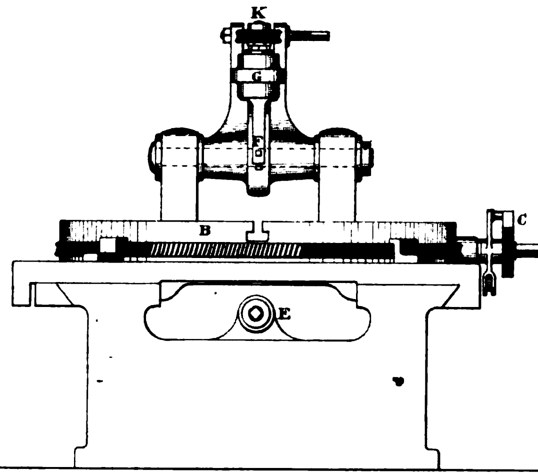


Fig. 6.

Front Elevation.



(Proceedings Inst. M.E. 1866. Page 280.) *Scale 1/20th* Inches 12 6 0 1 2 3 4 5 Feet.

CURVILINEAR SHAPING MACHINE. *Plate 102.*

Detail of Tool, enlarged.

Fig. 7.

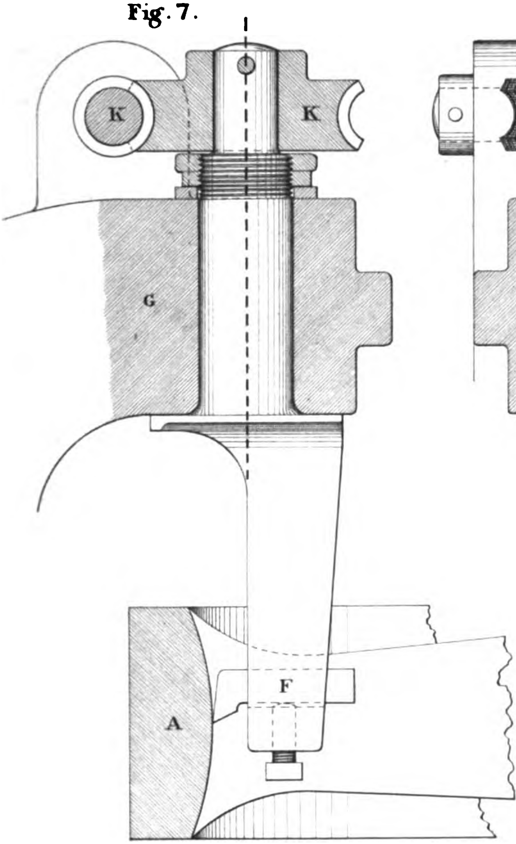


Fig. 8.

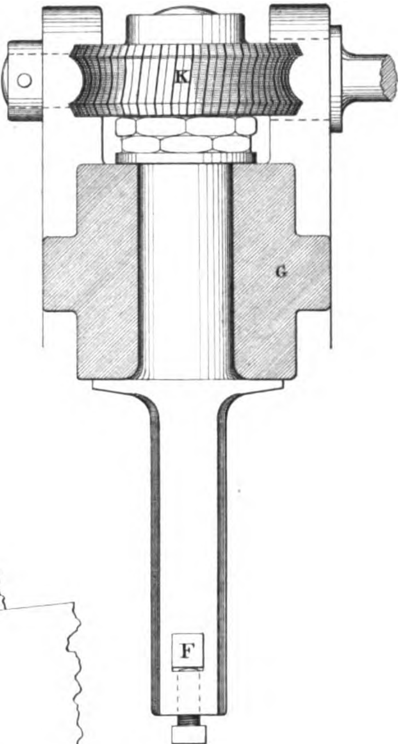


Fig. 9.

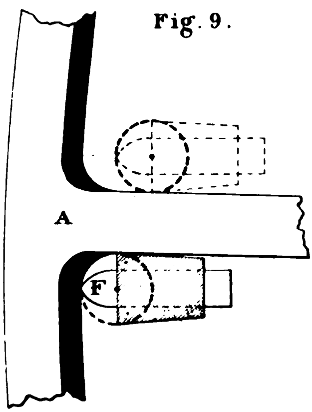
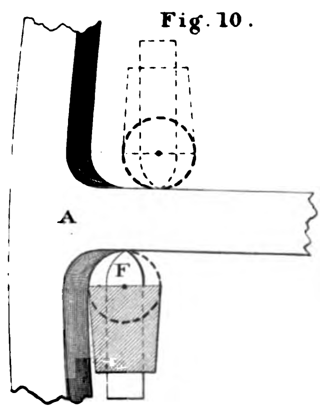


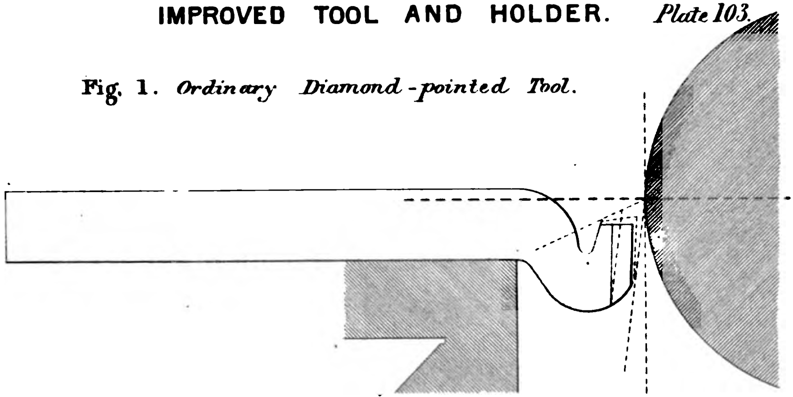
Fig. 10.



(Proceedings Inst. M.E. 1866. Page 280)

Scale 1/4th 0 1 2 3 4 5 6 7 8 9 10 *Inches.*

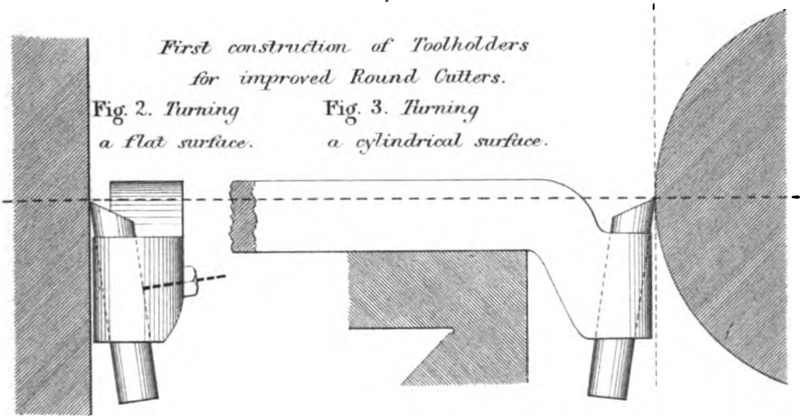
Fig. 1. *Ordinary Diamond-pointed Tool.*



First construction of Toolholders for improved Round Cutters.

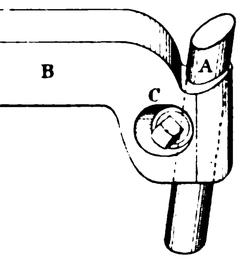
Fig. 2. *Turning a flat surface.*

Fig. 3. *Turning a cylindrical surface.*



Improved construction of Toolholder for Round Cutters.

Fig. 4. *Large size Tool and Holder.*



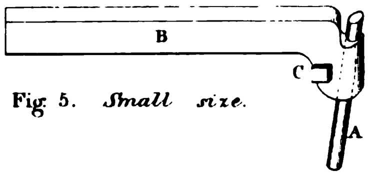
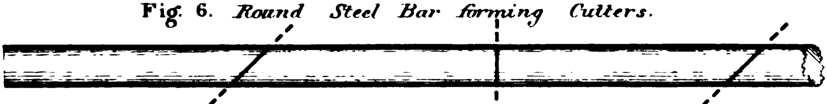


Fig. 5. *Small size.*

Fig. 6. *Round Steel Bar forming Cutters.*



(Proceedings Inst. M. E. 1866. Page 288.)

Scale 1/4 th. 0 1 2 3 4 5 6 7 8 9 10 *Inches.*

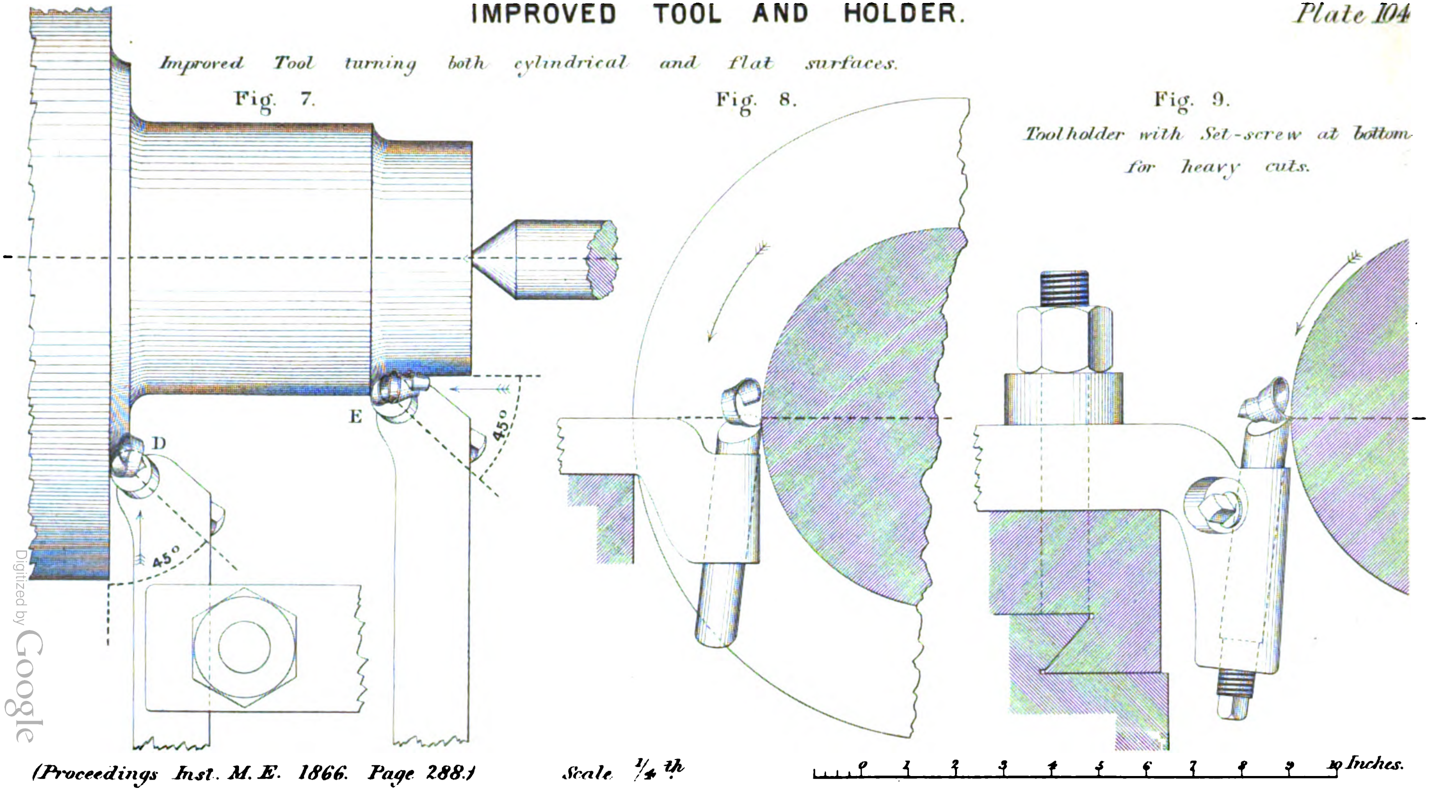
IMPROVED TOOL AND HOLDER.

Improved Tool turning both cylindrical and flat surfaces.

Fig. 7. Fig. 8.

Fig. 9.

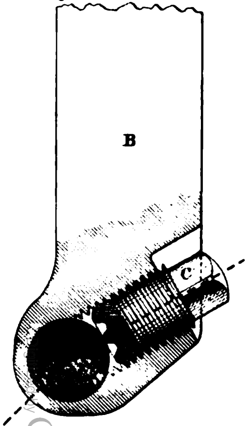
Toolholder with Set-screw at bottom for heavy cuts.



Scale 1/4 th

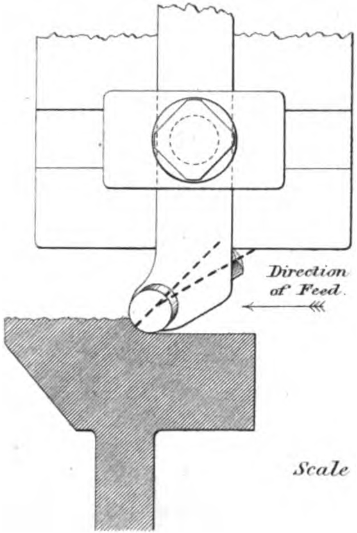
IMPROVED TOOL AND HOLDER.

Fig. 10. *Set-Screw fixing Tool in Holder.*



Scale 1/2

Fig. 11. *Tool planing flat horizontal surface.*



Scale 1/4 th

Tool Down-cutting vertical and inclined surfaces.

Fig. 12.

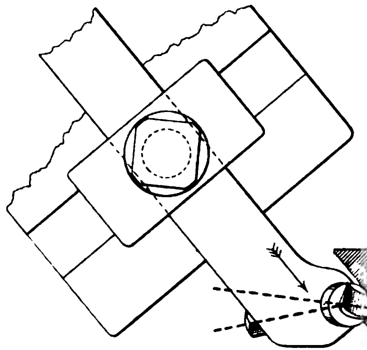
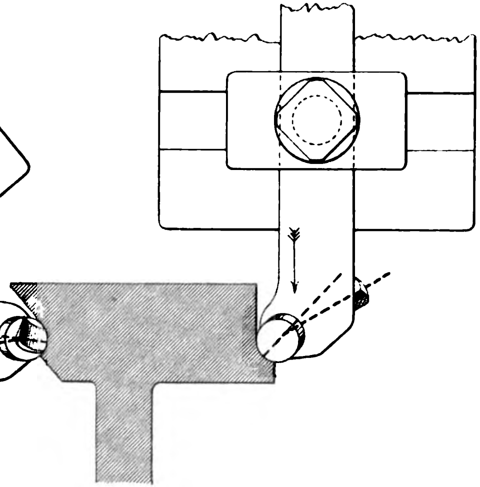


Fig. 13.



(Proceedings Inst. M. E. 1866. Page 288.) *Scale* 1/4 th

Fig. 14. *Gauge for adjusting Tool in lathe. Scale 1/4th*

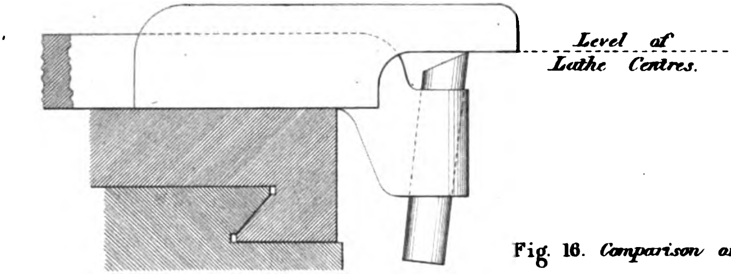


Fig. 15. *Angle Gauge. Half full size.*

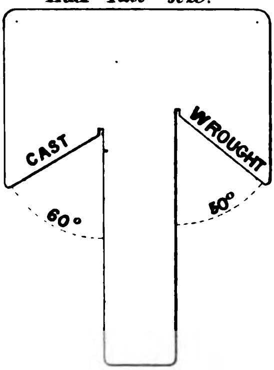


Fig. 16. *Comparison of ordinary diamond-pointed tool and improved round cutter. Scale 1/4th*

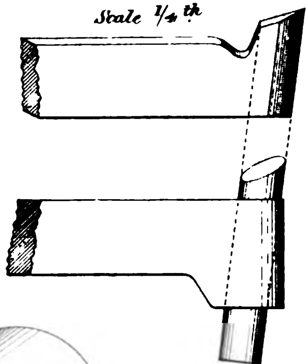


Fig. 17. *Surface produced by improved round cutter. Full size.*

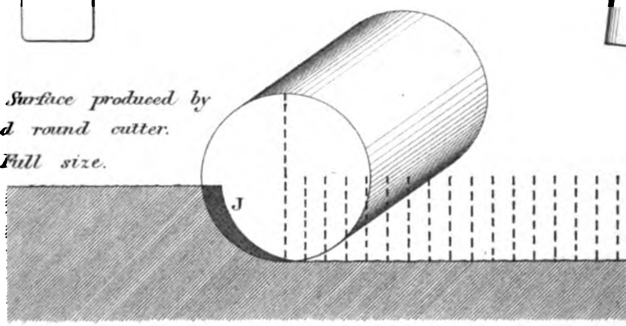
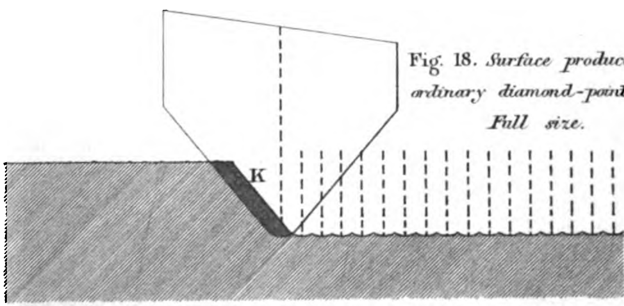


Fig. 18. *Surface produced by ordinary diamond-pointed tool. Full size.*



IMPROVED TOOL AND HOLDER.

Grindstone for grinding Tools.

Scale 1/12th.

10 5 0 10 20 Inches.

Fig. 19. *Front Elevation.*

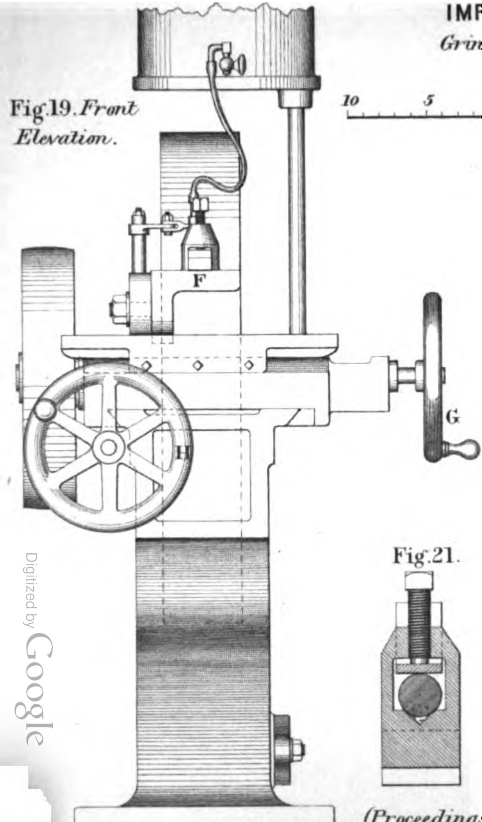


Fig. 20. *Side Elevation.*

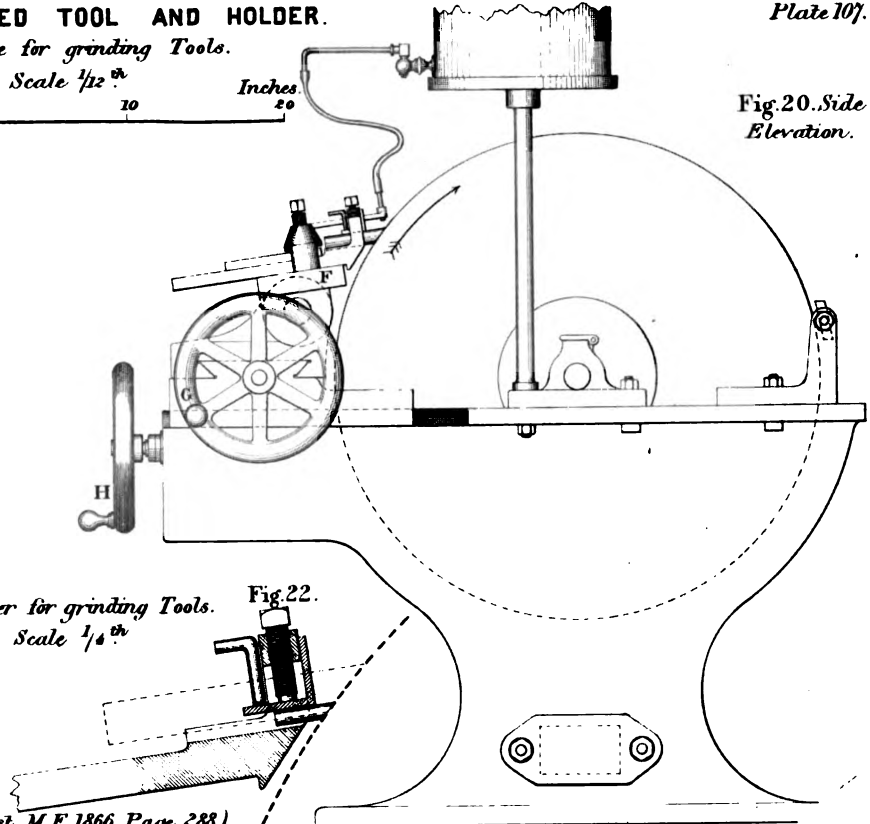


Fig. 21.

Holder for grinding Tools.

Scale 1/4th.

Fig. 22.

ar 78.